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CONTENTS

PLATES

INDEX MAP
OF
ECONOMIC MINERALS
IN
CALIFORNIA
AND THE
DISTRICTS OF THE DIVISION OF MINES
SCALE
0
50
100
200 MI.
CALIFORNIA STATE DIVISION OF MINES
1943
DISTRICT OFFICES OF THE DIVISION OF MINES
San Francisco (main office)
Los Angeles
Sacramento
Redding
BOUNDARIES OF THE DISTRICTS
OREGON
NEVADA
124°
123°
122°
121°
120°
119°
118°
117°
116°
115°
114°
42°
41°
40°
39°
38°
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
REDDING
TEHAMA
PLUMAS
BUTTE
GLENN
SIERRA
MENDOCINO
YUBA
NEVADA
PLACER
LAKE
COLUSA
SUTTER
EL DORADO
YOLO
SACRAMENTO
ALPINE
SONOMA
NAPA
AMADOR
SOLANO
CALAVERAS
MARIN
SAN JOAQUIN
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TUOLUMNE
SAN FRANCISCO
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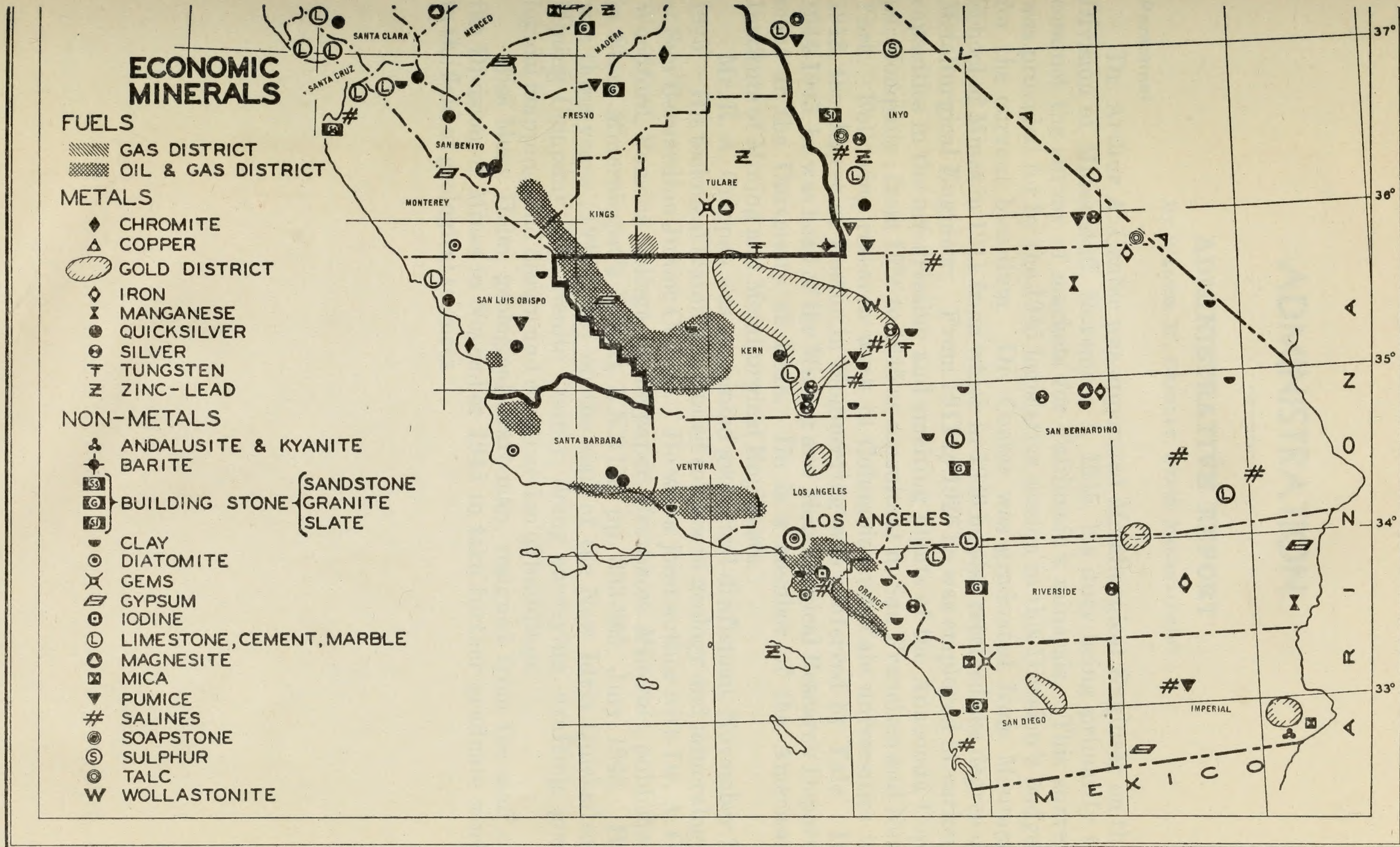
ALAMEDA
SAN MATEO
STANISLAUS
MARIPOSA


ECONOMIC MINERALS
FUELS
GAS DISTRICT
OIL & GAS DISTRICT
METALS
CHROMITE
COPPER
GOLD DISTRICT
IRON
MANGANESE
QUICKSILVER
SILVER
TUNGSTEN
ZINC-LEAD
NON-METALS
ANDALUSITE & KYANITE
BARITE
BUILDING STONE
SANDSTONE
GRANITE
SLATE
CLAY
DIATOMITE
GEMS
GYPSUM
IODINE
LIMESTONE, CEMENT, MARBLE
MAGNESITE
MICA
PUMICE
SALINES
SOAPSTONE
SULPHUR
TALC
WOLLASTONITE
SANTA CLARA
MERCED
SANTA CRUZ
MADERA
FRESNO
SAN BENITO
INYO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
MEXICO
ARIZONA
37°
36°
35°
34°
33°

ADMINISTRATION

ADMINISTRATIVE REPORT

By Walter W. Bradley, State Mineralogist

Personnel

Dr. Arthur A. Center was appointed Metallurgical Engineer on the Division of Mines staff, November 1, 1945, his duty being primarily to conduct the survey of markets for California's minerals. This survey was provided for by the 1945 legislative session in this Division's budget for the current biennium. Dr. Center was graduated from Montana School of Mines in 1911 from which in 1936 he also received the degree of Metallurgical Engineer. From 1911 to 1926 he was employed in various capacities in the ore-dressing and smelting plants of the Anaconda Copper Company; from 1926 to 1945 as consultant in San Francisco and New York. Following research work in Columbia and Yale universities in 1943, the degree of Doctor in Engineering was conferred by Yale. In 1944-1945, he was head of the Mining and Metallurgical Research Department of the University of Utah. He is a member of the American Institute of Mining and Metallurgical Engineers.

Mr. R. A. Crippen was appointed geological draftsman, November 7, 1945. His technical training included courses in geology and mineralogy at San Bernardino Junior College. He was a joint author with Dr. A. O. Woodford, Pomona College, in the paper, *Crestmore Minerals,* published in State Mineralogist's Report XXXIX, pp. 333-365, July 1943. He was three years (1942-1945) on the staff of the New Idria Quicksilver Mining Company, San Benito County, doing surveying, drafting, geological mapping, and design and construction of buildings.

Miss Mary Helm, geological draftsman, resigned from the staff of the Division of Mines in November 1945 to take further graduate work in the field of geological sciences.

GEOLOGIC BRANCH

CURRENT NOTES

By Olaf P. Jenkins *

Advance publication

Bulletin 129, *Iron Resources of California,* is now partly completed, and several parts have been issued in advance of the final bound volume: Part A, Eagle Mountains; Part B, Iron Mountain (Lava Bed District); Part C, Iron Mountain and Iron King (Silver Lake District); Part D, Old Dad Mountain; Part E, Cave Canyon; Part F, Vulcan; Part G, Iron Hat (Ironclad); Part H, Ship Mountains; Part I, Minarets; Part J, Hirz Mountain.

In this issue

The geology of one of the blank areas on the Geologic Map of California appears in this issue as a contribution from Lawrence B. Wright, *Geology of Santa Rosa Mountain Area, Riverside County.* The work was done during an investigation of the tungsten resources of the region.

Two geologic reports contributed by the United States Geological Survey, describing nickel and tin deposits in California, are published in the issue: *Geology and Nickel Mineralization of the Julian-Cuyamaca Area, San Diego County,* by S. C. Creasey, and *Tin Deposits of the Gorman District, Kern County,* by J. H. Weise and Lincoln R. Page.

In press

The following reports contributed by the United States Geological Survey are now in press: *Quicksilver Deposits of the New Idria District,* by E. B. Eckel and W. B. Myers, and *Quicksilver Deposits at the Sulphur Bank Mine, Lake County,* by D. L. Everhart.

In preparation

Two more quicksilver reports by the United States Geological Survey will be published in a forthcoming issue of the *Journal.* These cover the Eastern Mayacmas district (by R. G. Yates and L. S. Hilpert) and the Western Mayacmas district (by E. H. Bailey).

The first chapter of a new bulletin on the chromite deposits of the Klamath Mountains has been received from the United States Geological Survey. This is *The Chromite Deposits of Del Norte County,* by F. G. Wells, F. W. Cater, Jr., and G. A. Rynearson.

* Chief Geologist, California State Division of Mines.

GEOLOGY OF SANTA ROSA MOUNTAIN AREA, RIVERSIDE COUNTY, CALIFORNIA*

By Lawrence B. Wright **

OUTLINE OF REPORT

ABSTRACT

Rocks in the vicinity of Santa Rosa Mountain, Riverside County, consist of Paleozoic and pre-Cambrian (?) metasediments, and igneous intrusives. Five intrusives were mapped, only one of which, the "late granite," effected any tungsten mineralization.

INTRODUCTION

The area mapped in this special investigation comprises the whole of T. 7 S., R. 5 E., S. B., in Riverside County, California. Because of the rugged topography, the surface area probably totals 50 square miles. Elevations range from 3,500 to 8,705 feet, the high point being Toro Peak in the southeastern part of the township.

The drainage pattern is to a large extent controlled by geologic structure. Omstott and Deep Creeks, flowing northwest and northeast respectively, arc around the southern part of Sugar Loaf Mountain. Garnet Queen Creek flows southwestward in a canyon cut through faulted schists. Tributaries and headwaters frequently cut across rock trends, but as the streams gain volume, their courses assume directions of bedding, shearing, and contacts.

GENERAL GEOLOGY

Igneous Rocks

Three-fourths of the area of this township is typified geologically by intrusive rocks. They range in composition from basic rocks, rich in ferromagnesian minerals, to acid rocks, such as the highly siliceous, finely crystalline alaskite in section 13. Five intrusives were mapped: (1) old granite; (2) granodiorite; (3) late granite; (4) alaskite; and (5) granite of Sugar Loaf Mountain.

Granite of Sugar Loaf Mountain. The granite of Sugar Loaf Mountain occurs in sections 1 and 2, and extends northward past the boundaries of the township. It is coarsely crystalline and is characterized by uniformly distributed biotite, which makes up 10 to 15 percent of the rock. Phenocrysts lack stress orientation, and the granite is fresh in appearance.

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* Report released through courtesy of Mack C. Lake, vice-president, Manganese Ore Company, San Francisco.

** Consulting mining geologist, San Francisco. Manuscript submitted for publication November 28, 1945.

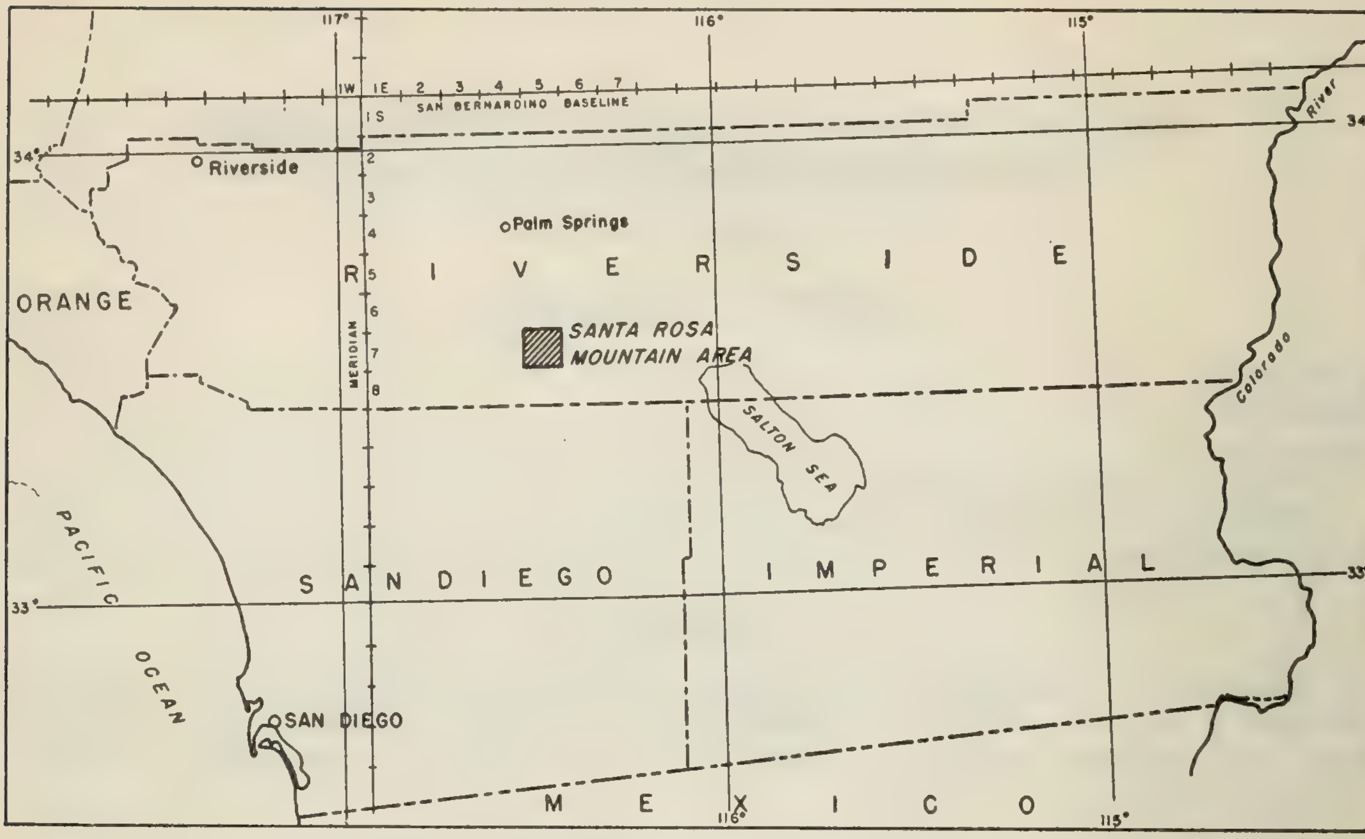


FIG. 1. Index map showing location of Santa Rosa Mountain area, Riverside County, California.

The granite of Sugar Loaf Mountain invaded a heterogeneous complex of older plutonics and sediments, forming a broad marginal metamorphic zone in which metamorphic minerals are generally lacking. Contact effects were mainly mechanical, although some bleaching of the invaded rocks is evident.

Late Granite. In the southern, and particularly in the middle western part of the township, the ''late granite'' is predominant. It intrudes a complex of sediments, ''old granite'' or granodiorite, and mica schist, but is believed to be older than the granite of Sugar Loaf Mountain and the alaskite. Its texture is finer than that of the Sugar Loaf outcrops, and it contains a larger proportion of ferromagnesian minerals. Post-emplacement movement is suggested by mild shearing along contacts and attenuation of northwest-pointing apophyses in sections 7 and 8.

During the investigation of tungsten resources of the township, it was noted that distribution of tactite (scheelite-bearing in some places) closely followed the contact zones of the late granite, which is the intrusive responsible for such scheelite mineralization as occurs in the area.

Granodiorite. Granodiorite occurs mainly in sections 3, 4, 5, 10, and 15, in the north-central part of the township. This rock is intensely sheeted. It is rich in hornblende and pyroxene, and may be more nearly basic than the field classification indicates. Its age relationship is readily discernible. It is cut by the granite of Sugar Loaf Mountain and by alaskite, and is definitely more sheared, folded, and contorted than any except the ''old granite.'' It was subject to the same structural deformation as the rocks it invaded, and its relationship to these indicates that it was probably a sill-like body.

Other Igneous Rocks. Aplite dikes and quartz veins are sparse. These, together with some pegmatite, outcrop in the flat near the village

A, VIEW NORTHWEST FROM NEAR WEST CENTER SEC. 24
SANTA ROSA MOUNTAIN AREA, RIVERSIDE COUNTY

Elevation approximately 6600 feet. Note gentle topography of sedimentary outcrops at left as opposed to rugged alaskite outcrops at right.

B, VIEW N. 35° E. TOWARD INDIAN WELLS, SANTA ROSA MOUNTAIN AREA, RIVERSIDE COUNTY

Looking down Deep Canyon from near north center sec. 23. Sugarloaf Mountain at left; canyon is cut approximately along granite-sedimentary contact.

C, VIEW N. 15° W. ACROSS PINYON FLAT TOWARD ASBESTOS MOUNTAIN, FROM NEAR CENTER SEC. 23, SANTA ROSA MOUNTAIN AREA, RIVERSIDE COUNTY

Nightingale is at broad cleared area in center in sec. 3. Readily disintegrating granodiorite has given rise to the comparatively even topography of the "flat." Rocks in foreground are mainly from massive schist outcrops in which no tactite was observed in this immediate area.

D, VIEW ABOUT N. 20° W., FROM NEAR CENTER SW¼ SEC. 16, SANTA ROSA MOUNTAIN AREA, RIVERSIDE COUNTY

Elevation 6000 feet. Shows Omstott Creek drainage leading into Palm Canyon. Asbestos Mountain in right background. Low, light-colored ridges extending nearly across center are composed of the marmarized white limestone shown on geologic map. Palm Springs is almost visible at light strip opposite mouth of canyon.

of Nightingale. Ultrabasic rocks occur in the northwest part of the township (sections 4 and 5), but their relationship is not known. They are not shown on the map, as the area of outcrops is relatively small.

Metasediments

With the exception of Recent alluvial material, the youngest metasedimentary rocks in the region are Paleozoic. These include thinly bedded phyllites and shale, and have for a key horizon a band of marmarized nonfossiliferous limestone that extends from the head of Palm Canyon in section 6, through section 8 and into section 9, where it is cut by granodiorite. It outcrops again in sections 11 and 12. Dips are consistently northeast and north about 45 degrees.

This series lies in a graceful arc around the north row of sections, greatly influencing drainage and topography; this is particularly true where the canyon of Deep Creek is sharply carved through section 12.

Older metasediments outcrop in the southwest portion of the township, striking east-northeast and dipping steeply to the north-northwest. These rocks are typical Paleozoic quartzites and argillites with thin calcareous beds. They are cut abruptly in their northeast trend, in section 30, by the ''late granite.'' Some of the lenses of calcareous rock have been altered to tactite in this part of the area.

The oldest metasediments in the township strike eastward toward Santa Rosa Mountain, and swing southeastward toward Toro Peak, through sections 19, 20, and 27 to 36. They are mainly mica-hornblende schists intercalated with thin tongues of the ''old granite.''

Outcropping along the northeast flank of Toro Peak and extending northwestward through section 14 is a belt of ferruginous phyllites lacking calcareous members except for some small broken lenses up to 150 feet in aggregate length, in section 14. These have been altered to tactite and contain some scheelite. Deep in the series and near the anticlinal axis in sections 25 and 27 are some thin tactite lenses of similar individual extent and character. The development of tremolite in the lenses in section 25 and toward Toro Peak is in contrast with the predominance of olivine and diposide in the tactite type of alteration. Scheelite is absent from the hornblende-rich phase.

Tabulation of sedimentary strata observed in T. 7 S., R. 5 E., S. B.

Age		*Thickness* (feet)*	*Type occurrence (section)*
Paleozoic	Shale and phyllite	1,800	5, 8
	Marmarized limestone	200	6, 8, 9
	Shale	700	8, 9
	Ferruginous phyllite; calcareous lenses near top and bottom	2,000	8, 14, 16, 18, 20, 24, 25
	Argillite, sandy buff	1,600	30
	Calcareous phyllite and dark schist	1,500	30, 31
	Quartzite	600	31
Pre-Cambrian?	Hornblende-mica schist, some ferruginous bands	1,800	30, 29, 28, 27, 26
		10,200	

* Thicknesses are approximations, as some repetition by faulting and folding is present.

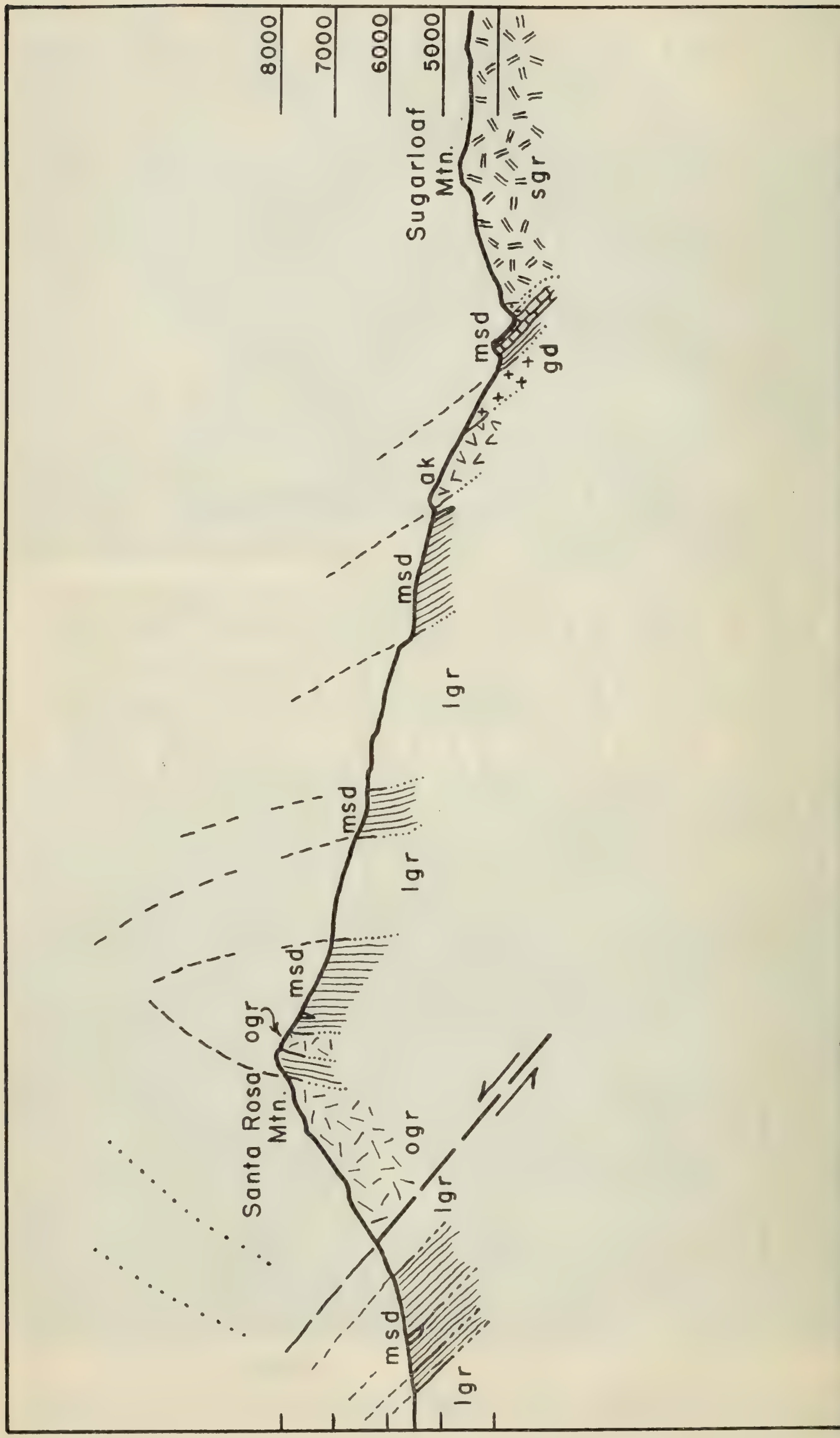
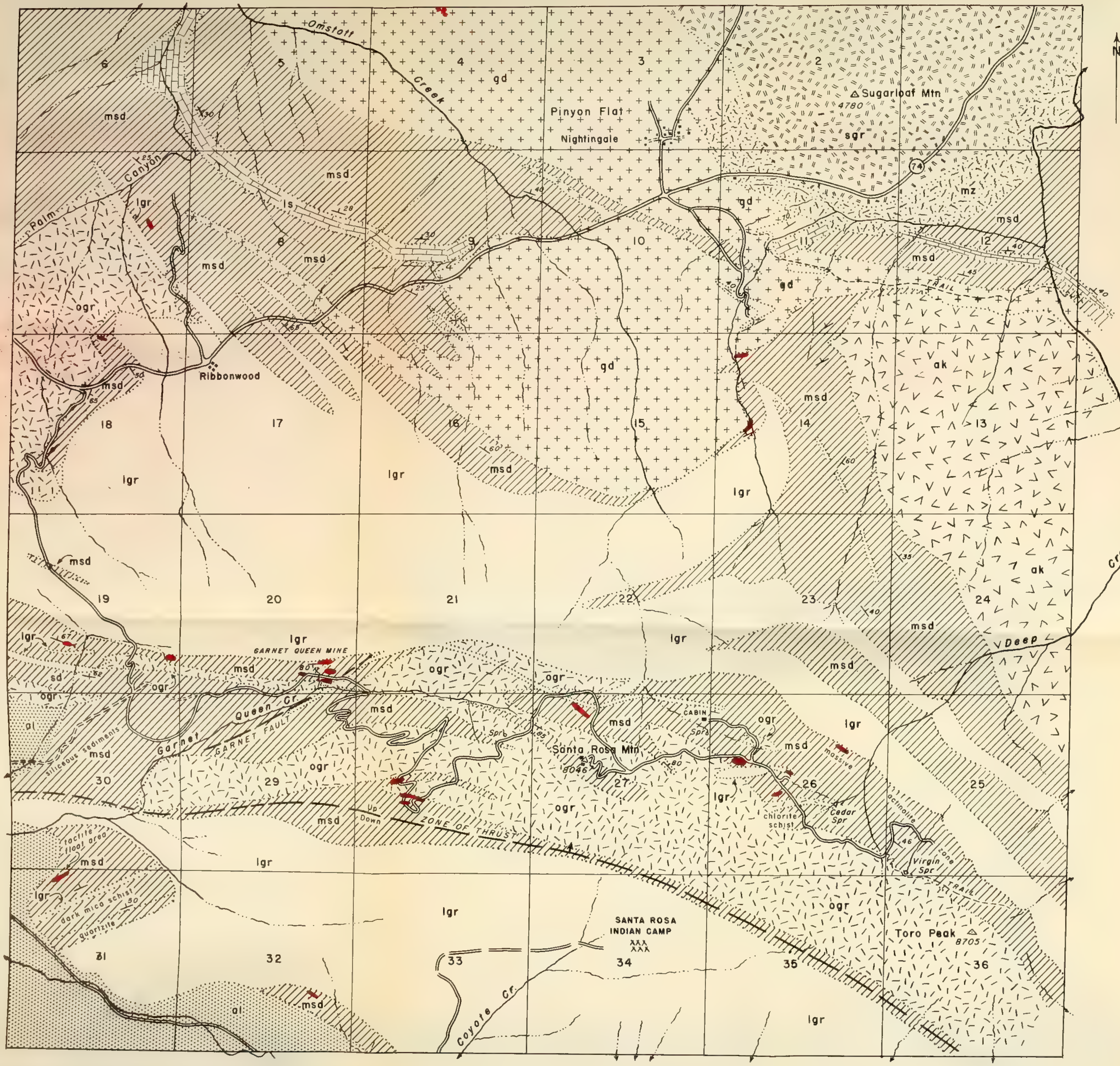


Fig. 2. Structural section through T. 7 S., R. 5 E., S.B., Riverside County, California. No structural section through the area in any direction would give the complete rock sequence; therefore the section above is somewhat idealized. The quartzite and associated rocks outcropping in the southwestern portion lie below the thrust plane and hence are brought eastward to the section to illustrate the relationship. Other thrusts are suggested along the north flank of the major fold.



GEOLOGIC MAP
OF THE
SANTA ROSA MOUNTAIN AREA
TOWNSHIP 7 SOUTH, RANGE 5 EAST
SAN BERNARDINO MERIDIAN
RIVERSIDE COUNTY, CALIFORNIA

BY Lawrence B. Wright, Consulting Mining Geologist
Arthur O. Hall, Field Engineer
1944

LEGEND

al	**Alluvium.** Terrace deposits.
sgr	**Biotite granite.** Sparse hornblende, abundant quartz. Coarse sheared texture.
ak	**Alaskite.** White, granular, weathers tan. Outcrops rugged.
lgr	**Granite.** Normal compositon, unsheared near margin. Medium texture. Bold outcrops.
gd	**Granodiorite.** Massive to schistose, coarsely crystalline. Folded and sheared.
ogr	**Hornblende granite.** Medium texture, disintegrates readily. Thinly intruded into schists. Few outcrops prominent.
mz	**Metamorphic zone.**
ls	**Limestone.** White, marmarized.
msd	**Metasediments.** Mainly schistose to gneissic, chlorite and tourmaline schist predominate.
(red)	**Tactite.** Garnet, epidote, diopside, with occasional sparse scheelite.

0 1000 2000 3000 4000 5000 FEET

ECONOMIC GEOLOGY

The few small scattered quartz outcrops and siliceous rusty weathering tactite lenses attracted gold prospectors many years ago. The only digging of any consequence was in section 20 where a vertical shaft (Garnet Queen) was sunk about 150 feet and an adit started to connect at about the 100-foot level. There are a score of old shallow pits in the township, at various elevations. Some are dug in iron-stained shear zones, others in quartz stringer zones, and some in pegmatite. It was not within the scope of this investigation to sample these and other exposures for gold and other precious metals. In such a complex of plutonics and sediments the presence of precious metals would not be unexpected or surprising. The high-specific-gravity basic rock in sections 4 and 6 should be tested for platinum-group minerals.

Particular attention was given to the distribution of tungsten-bearing minerals and a function of the work was to study their distribution and relationship to igneous contacts. Distribution and continuity of calcareous beds and the type and extent of alteration and replacement were also studied in detail.

This study disclosed a distribution of tactite development in calcareous members of the phyllite, in direct relationship to the ''late granite'' (see plate 1). The absence of silicates or tungsten minerals in the marmarized limestone near the Sugar Loaf granite is in strong contrast. The ''old granite'' fostered only quartz veinlets and aplite dikes. The alaskite and diorite appear to have been devoid of differentiates or allied products responsible for any mineralization or alteration, at least within visible horizons.

GEOLOGY AND NICKEL MINERALIZATION OF THE JULIAN-CUYAMACA AREA, SAN DIEGO COUNTY, CALIFORNIA*

By S. C. CREASEY **
UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY

OUTLINE OF REPORT

SUMMARY AND RECOMMENDATIONS

The Julian-Cuyamaca area is in the San Diego Mountains, one of the Peninsular Ranges of southern California. It lies in San Diego County, about 3 miles south of Julian, and approximately 60 miles northeast of San Diego. The area was mapped, and its nickel mineralization studied, from March to June, 1944; the work was part of the U. S. Geological Survey's program of strategic mineral investigations.

The only mine in the area is the old Friday nickel mine, and the only other openings are a few shallow prospect pits and trenches, and five short diamond-drill holes. The original Friday shaft, sunk on an outcrop of gossan containing a few dollars per ton in gold, was abandoned and now is covered by dump material, but a later shaft, south of the old one, was accessible in 1944. Partly oxidized sulfide minerals were found on the 132-foot level and more massive sulfides on the 180-foot level, which is the lowest in the mine.

* Published by permission of the Director, Geological Survey, United States Department of the Interior, Washington, D. C. Manuscript submitted for publication November 1945.

** Geologist, Geological Survey, United States Department of the Interior.

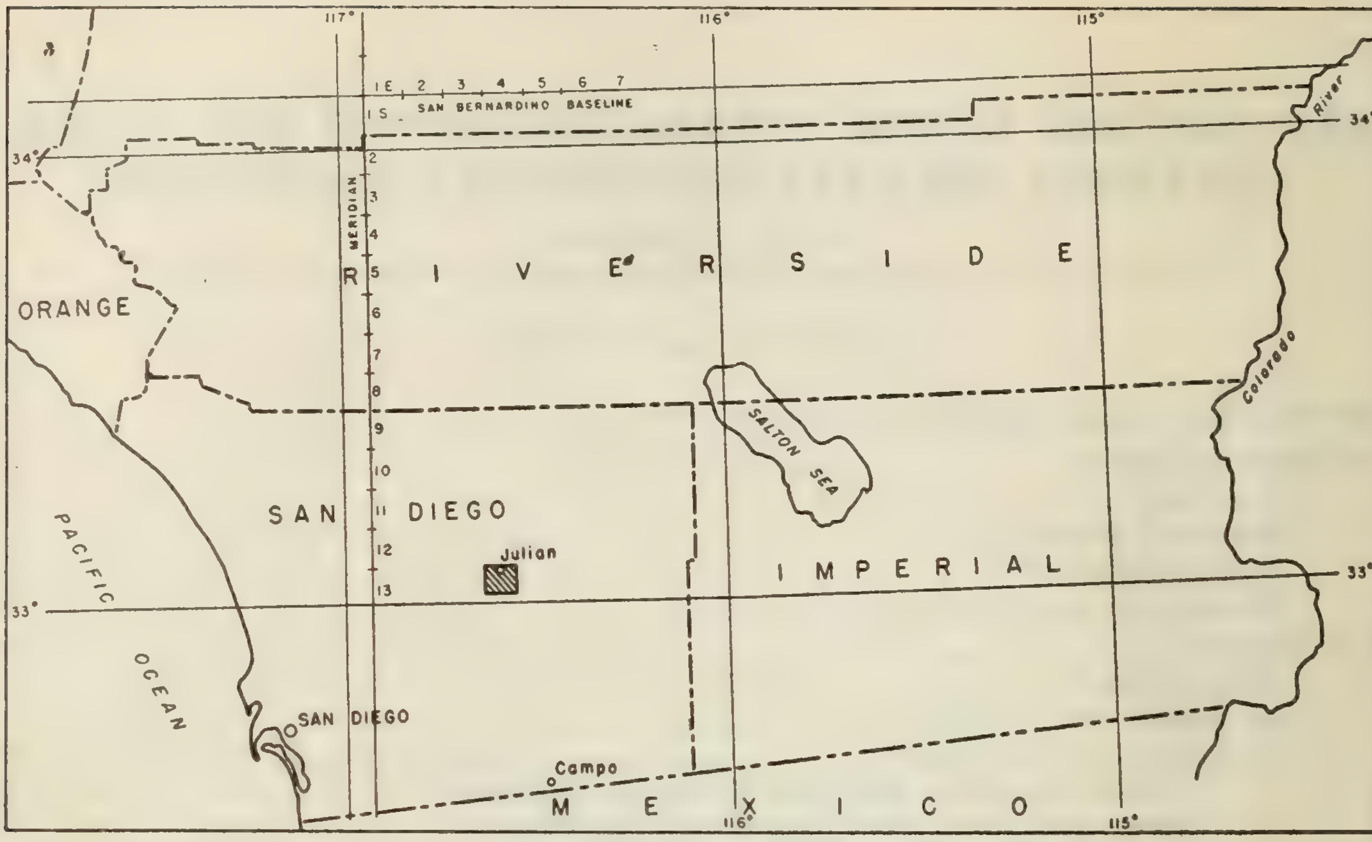


FIG. 1. Index map showing location of the Julian-Cuyamaca area, San Diego County, California.

Three major rock units are recognized in the area: the Julian schist, probably of Triassic age; the Stonewall quartz diorite, which is intrusive into the schist; and the Cuyamaca gabbro group, which is younger than the quartz diorite. The rocks in this group range from gabbro and norite, to periodotite and pyroxenite. The Friday mine contains the only body of sulfides exposed in the area, though gossan outcrops and float in the Inspiration Point and Pine Hills salients of the Cuyamaca gabbro group indicate other mineralized zones of unknown but probably small size.

The mineralized zone at the Friday mine is irregular in shape. Where exposed it is from 6 feet to over 20 feet wide and 55 feet long; its depth has not been fully determined. Assuming an average width of 15 feet and a length of 55 feet, there is estimated to be approximately 5,000 tons of indicated ore in a block between the 132- and 180-foot levels of the Friday shaft. Below the 180-foot level the ore body contains about 90 tons of inferred ore per foot of depth for a limited distance. The average for all assays from both oxidized and unoxidized rock is about 2.0 percent Ni, but the sulfide ore will probably average between 2.5 and 3.0 percent nickel and between 0.5 and 1.0 percent copper. As much as 0.15 percent cobalt is found in some of the massive sulfide and the sulfate resulting from oxidation of the ore, but the average cobalt content is not known. The sulfide minerals recognized in the Friday deposit are pyrrhotite, pentlandite, violarite (NiS_2), pyrite, and chalcopyrite.

Samples of gossan from the dump of the Friday mine and from the Inspiration Point area in the Pine Hills contain from .03 to 1.45 percent nickel.

Additional small bodies of nickel ore may be found by further exploration, but the remoteness from railways would make it difficult to mine economically nickel deposits of small mine tonnage, and the known occurrences of ore give little hope of developing economically large low-

DIVISION OF MINES
WALTER W. BRADLEY, STATE MINERALOGIST
OLAF P. JENKINS, CHIEF GEOLOGIST

STATE OF CALIFORNIA
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GEOLOGICAL SURVEY

grade reserves, such as would justify the construction of a mill. The area would merit further study, however, if at any time in the future a general investigation of the nickel resources of the country were undertaken.

Before diamond drilling, trenching, or underground exploration are undertaken, the area should be further explored by geophysical methods, keeping in mind particularly the possible influence of magnetic materials locally concentrated in the soil.

INTRODUCTION

Location

The Julian-Cuyamaca area is in the San Diego Mountains, one of the Peninsular Ranges in southern California. It is 3 miles south of Julian, San Diego County, and approximately 60 miles northeast of San Diego, California. State highway 79 passes through the northeast corner of the area, and maintained oiled county roads serve the central and western parts. The nearest railroad station is at El Cajon, California, about 45 miles from Julian on the main road to San Diego.

Scope of Work

The field work in the Julian-Cuyamaca area was done by the writer and Robert M. Hutchinson from March 3 to the first of June, 1944. Using a triangulation network for control, approximately one square mile extending from south of the Friday mine north to Inspiration Point was mapped by plane table (pl. 3). In addition, 9 square miles, which includes the northern one-fourth of the intrusive Cuyamaca gabbro group and the adjacent schist and quartz diorite, were mapped in less detail on aerial photographs (pl. 2). Detailed mapping is difficult because of thick brush and local dense stands of evergreen and deciduous trees. In addition, the rocks comprising the Cuyamaca gabbro group are deeply weathered, and the only outcrops consist of residual boulders in a matrix of soil and rock fragments.

Acknowledgments

B. S. Butler visited the party and gave many helpful suggestions on the field work, and P. J. Shenon advised regarding general geophysical problems connected with nickel deposits. The Geological Survey laboratory in Washington, D. C., made all assays, mineral determinations, and magnetic separations of soil samples. Mineral determinations were by Charles Milton and nickel determinations by F. S. Grimaldi. The writer is indebted to Helen Cannon, M. D. Crittenden, and C. A. Anderson for critical reading of the manuscript.

Previous Geologic and Geophysical Work

Calkins (16), who visited the Julian area in 1916, described briefly the regional geology and the underground workings and mineralization of the Friday mine. Tolman and Rogers (16) studied a suite of sulfide specimens from the Friday mine. In summary they state, "In the Friday deposit we have the following sequence of events: (1) The crystallization of olivine, pyroxenes, and plagioclase. (2) A slight development of hornblende by magmatic alteration. (3) The formation of pyrrhotite, pentlandite, and chalcopyrite in the order named by

the replacement of the above mentioned silicates. (4) The development of tremolite as a hydrothermal mineral and the development of pentlandite of a second generation in cracks in pyrrhotite. (5) The extensive development of calcite and marcasite veinlets.'' Hudson (22) mapped the geology of the Julian district during 1917 to 1919 on a scale of one inch equals one mile. His report emphasizes areal geology but includes a description of the Friday mine and a discussion of the genesis of the ore, which he believed to be of syngenetic magmatic origin. Donnelly (34), who mapped the Julian district in the summers of 1932 and 1933, emphasized the economic importance of the gold-bearing quartz veins but only briefly mentioned the Cuyamaca gabbro and associated nickel mineralization.

Two private reports on the Friday mine were available to the writer, one by C. F. Tolman and Z. K. Melcon, and the other by H. J. Fraser. Melcon, during his examination of the Friday mine and the adjacent area, sampled the underground workings and systematically made qualitative soil analyses around the mine. Fraser, using a Schmidt-type vertical magnetometer, made a brief geophysical study of the area around the Friday mine and Inspiration Point.

GEOLOGY

Julian Schist

The Julian schist is the oldest rock in the area. Fairbanks (93), on the basis of lithologic correlation with formations in the Santa Ana Mountains containing a Triassic fauna, and Hudson (22, pp. 188-200), who found a Triassic ammonite, designated the Julian schist to be of Triassic age. In 1914, Merrill (14, p. 12) assigned the name of ''Julian group'' to the crystalline schists in San Diego County and cited the schists near Julian as typical, especially of the mica schists. Subsequently, Hudson gave the formation name, Julian schist, to the rocks in the Julian area.

The Julian schist crops out over a known length of more than 12 miles and a width ranging from three-quarters of a mile to 1½ miles. It is a meta-sedimentary series composed chiefly of quartz-mica schists, quartzite, and locally of a relatively coarse-grained quartz-biotite gneiss that is in places very similar to the gneissoid phase of the younger Stonewall quartz diorite. The quartz-biotite gneiss may be an injection gneiss or possibly a meta-tuff. The degree of metamorphism is moderate, corresponding to the ''biotite grade,'' but local areas of more intense metamorphism are indicated by two localities of mica-sillimanite schist.

The quartz-mica schists, the most abundant metamorphic rocks, are of three types; quartz-biotite schists, quartz-biotite-muscovite schists, and quartz-muscovite schists, listed in order of abundance. They have a strong schistosity which is roughly parallel to the original bedding wherever the latter is discernible in adjacent quartzite members. Quartz and feldspar are always present, and commonly they make up about half of the rock.

The quartzites are in lenses of variable length and thickness ranging from less than one foot to over 500 feet, as shown in the quartzite zone 1500 feet west of Inspiration Point. Muscovite-quartz schists usually are associated with the quartzite. Relic sedimentary structures such as cross bedding are visible in some of the quartzites.

No nickel mineralization is known to occur in the main mass of Julian schist; however, nickel mineralization and gossan are in Cuyamaca gabbro adjacent to schist inclusions in the Friday mine and near coordinate 7500N—10000E (pl. 3). Julian schist is the host rock for part of the gold-bearing quartz veins in the Julian district.

Stonewall Quartz Diorite

The Stonewall quartz diorite is a unit of the large mass of granitic rock that comprises much of the Peninsular Range in San Diego County. Because of the uncertain age relations of similar rocks in adjacent areas, a new formation name was given to it by Hudson (22, p. 19) after Stonewall Peak, which is composed of this quartz diorite. The Stonewall quartz diorite intrudes the Julian schist and is probably of Mesozoic age. It is a host rock for gold-bearing quartz veins in the Julian district but is not known to contain nickel deposits.

The Stonewall quartz diorite is composed of biotite, quartz, feldspar, and commonly a little sulfide, probably pyrite. Hudson reports the feldspar to be predominantly plagioclase, varying from albite to andesine, with subordinate amounts of orthoclase. In the Julian-Cuyamaca area the quartz diorite is locally gneissoid, and, where it approaches a true biotite gneiss in texture and structure, it is difficult to separate from the coarse-grained para-gneiss of the Julian schist.

Cuyamaca Gabbro Group [1]

The Cuyamaca gabbro, originally described as the "Cuyamaca basic intrusive" (Hudson 22, p. 193), is the youngest formation in the area and is intrusive into the Julian schist and Stonewall quartz diorite. The outline of the intrusive complex is irregular, but in general it is elongate to the north with the length about three times the average width; its areal extent is about 25 square miles. Approximately the northern one-fourth of the Cuyamaca gabbro was mapped.

The principal rock types comprising the Cuyamaca gabbro, as determined by hand-lens examination, are peridotite, pyroxenite, norite, gabbro, lamprophyre dikes, and related rocks. Hypersthene diorites and augite diorites were reported from the area by Hudson (22, p. 193) on the basis of microscopic determination of the feldspar composition. Fine-grained lamprophyre dikes are common and some of them are large, but it was not feasible to map them because of poor outcrops. Plagioclase feldspar, olivine, augite, hypersthene, and brown hornblende, in varying proportions, constitute over 90 percent of these rocks. In addition, the rocks contain as much as three percent pyrrhotite, a little magnetite, and a trace of green spinel. Uralite (?), a secondary amphibole, commonly occurs as reaction rims around olivine and pyroxenes.

The Cuyamaca gabbro was subdivided in the field on the estimated content of feldspar, and, where possible, further subdivisions were based on the ferromagnesian minerals. Other members might be separated on textural differences with additional mapping. The subdivisions are purely arbitrary, and the units are generalized and include exceptions, as the contacts are necessarily gradational and arbitrarily placed.

[1] After this paper was in proof, Merriam published an article in which he used the term "San Marcos gabbro" for the rocks that include the Cuyamaca gabbro group herein described. (Merriam, R. 46; see also Hurlbut, C. S., Jr. 35, and Miller, F. S. 37, 38.)

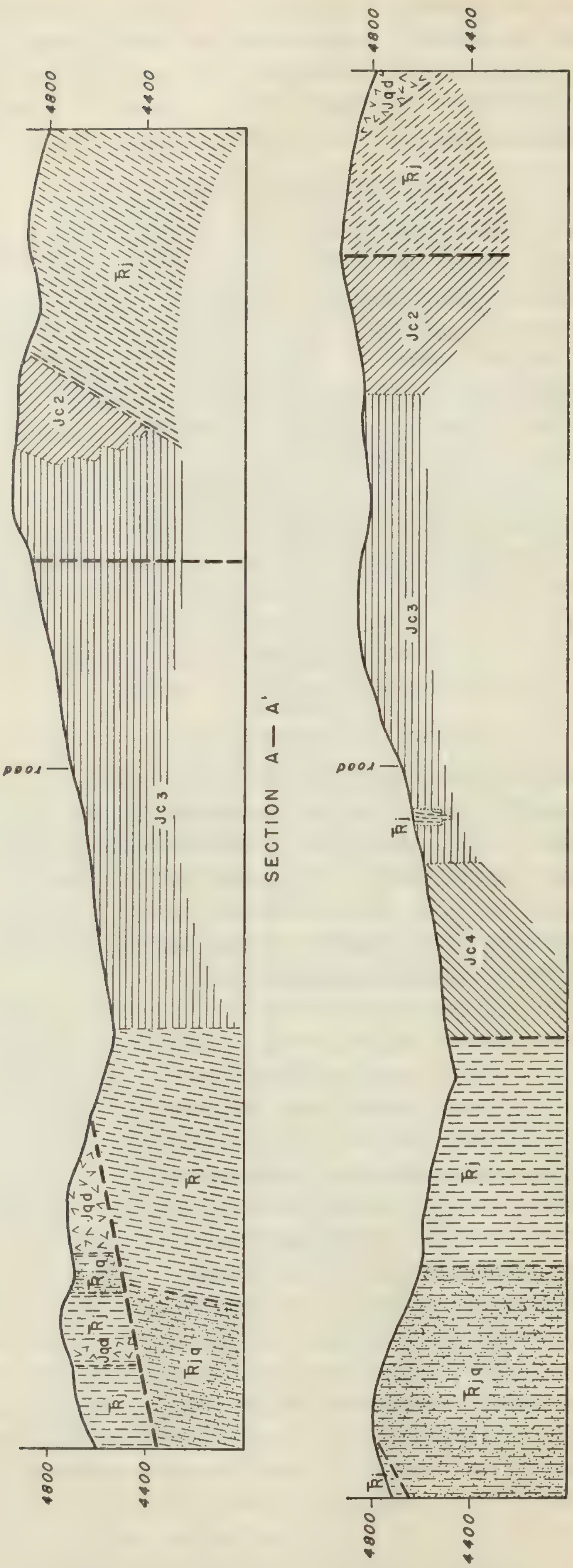
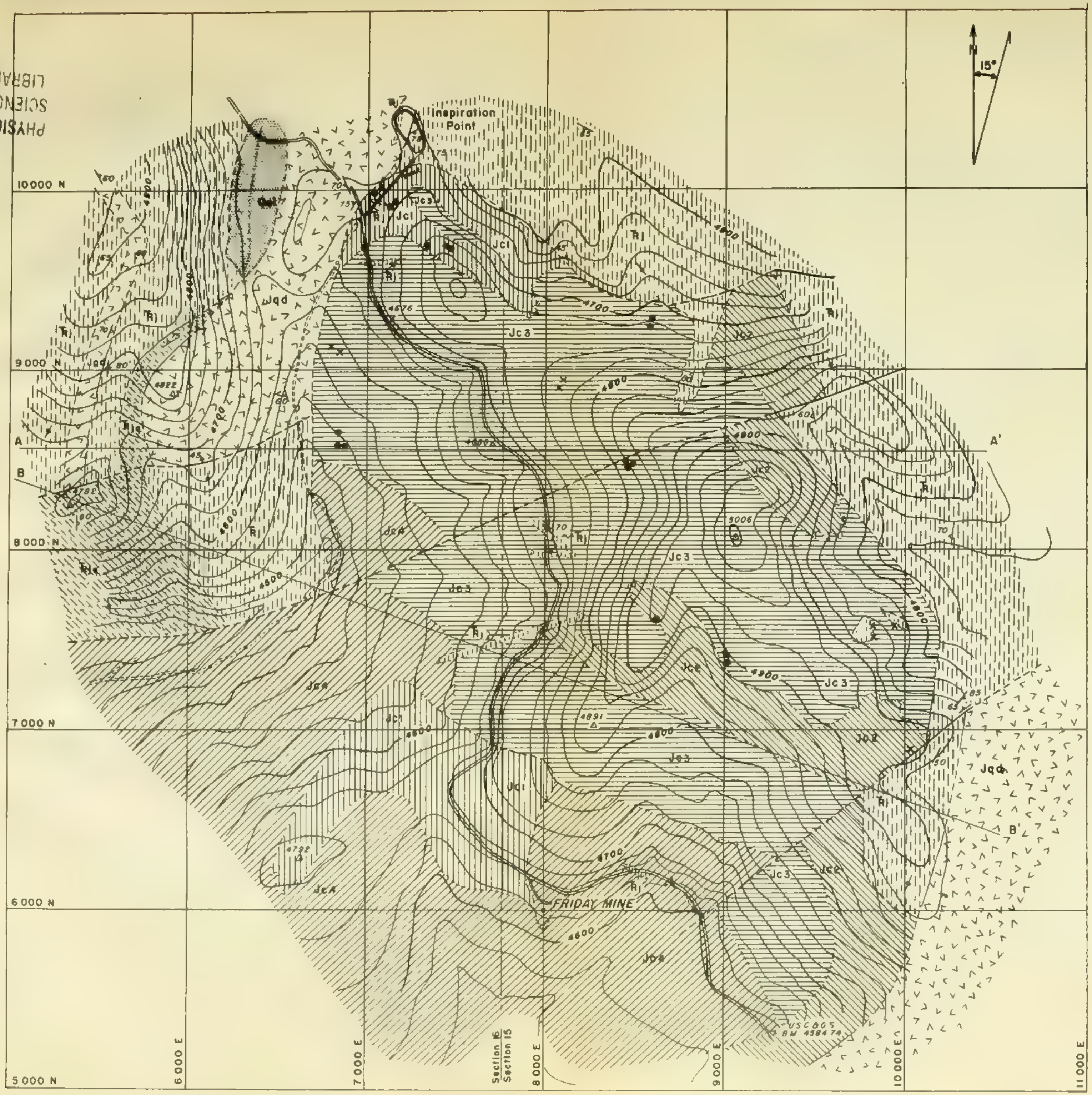


Fig. 2. Geologic sections, Friday mine—Inspiration Point area.



GEOLOGIC AND TOPOGRAPHIC MAP

FRIDAY MINE — INSPIRATION POINT AREA

NEAR JULIAN

SAN DIEGO COUNTY, CALIFORNIA

TOPOGRAPHY AND GEOLOGY BY
S. C. CREASEY AND R. M. HUTCHINSON
JUNE 1944

EXPLANATION

QUATERNARY — Qal — Colluvium and alluvium

MESOZOIC — Cuyamaca gabbro: *gabbro, norite, diorite, peridotite, pyroxenite, and related rocks*
- Jc1 — *0-15% feldspar*
- Jc2 — *15-40% feldspar*
- Jc3 — *over 40% feldspar*
- Jc4 — *over 40% feldspar, olivine predominant ferromagnesian mineral*

Jurassic — Jqd — Stonewall quartz diorite

Triassic or older — Ȓj — Julian schist

" — Ȓjq — Julian quartzite

Chlorite-talc rock

xx Gosson outcrop

Gossan float

70 Foliation strike and dip

CONTACTS

Location certain

" uncertain

" concealed

Fault, location certain

" " uncertain

0 400 800 1200 1600 2000 FEET

An area from Inspiration Point south almost to the Friday mine, indicated on the 400-scale map (pl. 3) by the overlay pattern, was differentiated because of the alteration of the ferromagnesian minerals, chiefly olivine and pyroxene. These minerals are partly to completely altered to fibrous, light green amphibole, presumably uralite, but the parent minerals commonly can be recognized as residual cores. This alteration is not uniform, being most complete at Inspiration Point and least complete along the ridges to the southeast. As nearly as can be determined by hand lens examination, the mineralogical composition of these rocks prior to the alteration of the ferromagnesian minerals to uralite (?) was similar to the normal gabbros and norites. Residual hypersthene, olivine, and brown hornblende enclosing other mineral grains are common and in some places are found in the same hand specimen. This altered area also contains the most gossan outcrops, float, and chlorite-talc rock. The association suggests that there may be a genetic relationship between the widespread rock alteration, which is not found extensively elsewhere in the region, and the later nickel mineralization.

Except for the uralite (?), which is probably of deuteric origin, the ferromagnesian mineral present apparently does not signify any difference in the parent magma but depends on the completeness of reaction. Where conditions were favorable for free exchange of elements and slow cooling of the magma, augite and hypersthene are the most abundant, whereas in other areas where the necessary reactions were impeded for one reason or another, olivine predominates. Local zones in the magma, however, were richer in iron and magnesium and are represented by the peridotites and mafic norites and gabbros.

Rocks Containing Less than 15 Percent Feldspar

The mafic norites and gabbros, pyroxenites, and peridotites constitute the phase of Cuyamaca gabbro containing less than 15 percent feldspar. They occur in three areas located (pl. 2): (1) northwest of the Friday mine, (2) the northern end of Inspiration Point, and (3) the western edge of Pine Hills, and they are all in salients extending into the schist and quartz diorite. The nickel-mineralized zone in the Friday mine and the gossan float near Pine Hills are associated, in part at least, with rocks of this composition.

The area extending northwest from the Friday mine is the largest of the three and is defined more clearly than the others by a sharp intrusive contact on the north and west between rocks of this phase and those containing over 40 percent feldspar. The rock is composed predominately of olivine and pyroxene, less than 15 percent feldspar, a small amount of amphibole, and here and there pyrrhotite, which composes up to 3 percent of the rock. Hudson (22, p. 200) reported peridotite from the 180-foot level of the Friday mine. The pyroxenes are black augite and brown to pink hypersthene, and the amphibole is brown hornblende in large crystals enclosing smaller grains of olivine, pyroxene, and feldspar. Olivine, although abundant and easily recognized, commonly has coronas of a light green mineral.

The Inspiration Point area is the smallest of the three. It lies roughly parallel to the contact between the Cuyamaca gabbro and schist country rock and less than 300 feet from it. The rocks of this area, being within the zone of uralitic (?) alteration, are partly to completely

altered to the light green fibrous amphibole. In the northern end of the area, the original mafic minerals appear to be wholly destroyed, but in the eastern and central sections the alteration is incomplete, leaving residual cores of olivine and pyroxene.

The rocks in the Pine Hills area are similar in appearance to those in the area near the Friday mine. The ratio of dark to light minerals is about the same in both areas, but the area near Pine Hills contains more olivine and less pyroxene. The contact of the Pine Hills area is gradational into the phase of Cuyamaca gabbro containing from 15 to 40 percent feldspar.

Rock Containing from 15 to 40 Percent Feldspar

The rock containing from 15 to 40 percent feldspar includes the intermediate types of the Cuyamaca gabbro. In general, the texture is similar to the more mafic types and is a little coarser than the rocks richer in feldspar. Black augite and brown hornblende containing inclusions of other minerals are the most abundant mafic minerals, and pyrrhotite is common in amounts up to 3 percent of the rock. The general distribution of these rocks is similar to that of the rocks containing less than 15 percent feldspar, both groups occurring in salients that extend into the country rock. Gossans occur in rocks of this phase in the Inspiration Point salient.

Rock Containing Over 40 Percent Feldspar

The phase of the Cuyamaca gabbro containing over 40 percent feldspar contains the most gossan outcrops and float and shows the greatest variation in rock texture and mineral composition. Its areal extent is at least five times that of any other member. The most persistent ferromagnesian minerals are hypersthene and brown hornblende with inclusions, yet augite and olivine are common, although not always present. Here and there hybrid phases occur near the contact with the Julian schist and the Stonewall quartz diorite. They are characterized by a high feldspar content, the presence of biotite, and little or no olivine or pyroxene. According to Hudson, some of these hybrid rocks contain a little free quartz.

The small isolated bodies near Deer Lake are slightly different from the average. They consistently contain from 40 to 50 percent feldspar and many brown hornblende crystals as large as 4 inches in length, but in other respects they are similar to the rocks in the salient to the southeast. The rocks cropping out along Cedar Creek show considerable range in grain size and variation in texture, such as the large brown hornblende crystals containing inclusions.

The member of the Cuyamaca gabbro at the southern end of the Inspiration Point salient was separated from the phase containing over 40 percent feldspar because of the consistent mineral composition, texture, and percentage of light and dark minerals. It is composed of 60-70 percent feldspar, approximately 25-35 percent olivine, locally a little pink hypersthene and brown hornblende, and from a trace to 3 percent pyrrhotite.

Pegmatite Dikes

Pegmatite dikes are common in all types of rocks, especially the Stonewall quartz diorite. Most of the dikes, being small and discontinuous, are represented by a single outcrop. Orthoclase and quartz

with some black tourmaline are the principal minerals in most of the dikes, but a few of the dikes contain muscovite nests. The largest and most continuous pegmatites are shown on plate 3.

The genetic association of the pegmatites was not determined with assurance because of the small size of the area mapped. However, the pegmatites may be of two ages related in part to the Stonewall quartz diorite and in part to the Rattlesnake granite, which is exposed several miles southeast of the area covered by this report and is thought by Hudson (22, p. 208) to be essentially contemporaneous with the Cuyamaca gabbro group. Presumably, the pegmatites found in the Cuyamaca gabbro would be related to this granite, whereas the pegmatites in the older rocks could be related to either the Stonewall quartz diorite or the Rattlesnake granite.

Lacustrine Deposit

The lacustrine deposit, as exposed in deep gullies, consists of interbedded sedimentary strata of varying composition and texture, including peat beds. The thickness of lake beds exposed in the gullies is estimated at 75 feet, but the total thickness is unknown. Presumably the lake was formed in Quaternary time by an upthrown fault block that dammed a small stream. Subsequent erosion cut a steep-walled canyon through the fault block, and the lake drained.

Colluvium and Alluvium

The areas mapped as colluvium and alluvium contain no outcrops and are composed of soil transported as much as several hundred feet from the source rock and of stream-deposited sediments. The alluvium and colluvium in sections 7, 8, 17, and 18 occur in an area of gently rolling hills separated by grassy fields and meandering streams of low gradient. This grassy upland, which is extensively utilized for fruit orchards and stock raising, lies at a higher elevation than much of the more rugged country and may represent the remnant of an older erosion surface.

Structure

The structural history of the Julian-Cuyamaca area includes folding, faulting, and intrusion. The recognizable folding is limited to the Julian schist and the gneissoid parts of the quartz diorite, but faults, with at least two periods of movement, cut all three units.

In general, the foliation in the Julian schist, which is parallel to the original bedding, and in the gneissoid Stonewall quartz diorite is parallel to the contact of the Cuyamaca gabbro; however, local areas with discordant contacts are common. As a result of this general parallelism, the salients of Cuyamaca gabbro are bounded by folds in the schist and gneissoid diorite. Such folds are clearly developed around the Pine Hills salient and the salient in sections 16 and 17. The schist, changing abruptly in dip from north to south at the boundary between sections 7 and 8, is overturned around Pine Hills. It cannot be stated positively, without mapping a larger area of Julian schist, whether the folding in the schist resulted from force of intrusion or whether the Cuyamaca was intruded into the axes of preexisting folds. The writer favors the former explanation as Hudson's map does not indicate any folds of comparable size in the schist except in the vicinity of the Cuyamaca gabbro.

Because of poor outcrops and uniform lithology of the Julian schist, the existence of faults is difficult to establish. All of the faults found are in or near the Inspiration Point salient, which was mapped in more detail with the hope of finding structures that might be important in the localization of ore bodies of epigenetic origin. Undoubtedly many faults could be found in other areas by more detailed mapping. The faults have high-angle dips and strike northeast as do the more important fractures in the Friday mine, and some of the faults have at least two periods of movement separated in time by the intrusion of the gabbro. The amount of movement preceding the intrusion of the gabbro is unknown, but undoubtedly it was greater than the post-gabbro movement, which has a strike-slip displacement ranging from about 300 to about 1500 feet. The two periods of movement on the fault exposed in the center of section 16 are established clearly by the wide quartzite band that is present in the Julian schist north of the fault. The quartzite band is not present in the offset part of the schist south of the fault. The distribution of the schist, quartz diorite, and gabbro along the faults in section 15 is also strongly indicative of two periods of faulting.

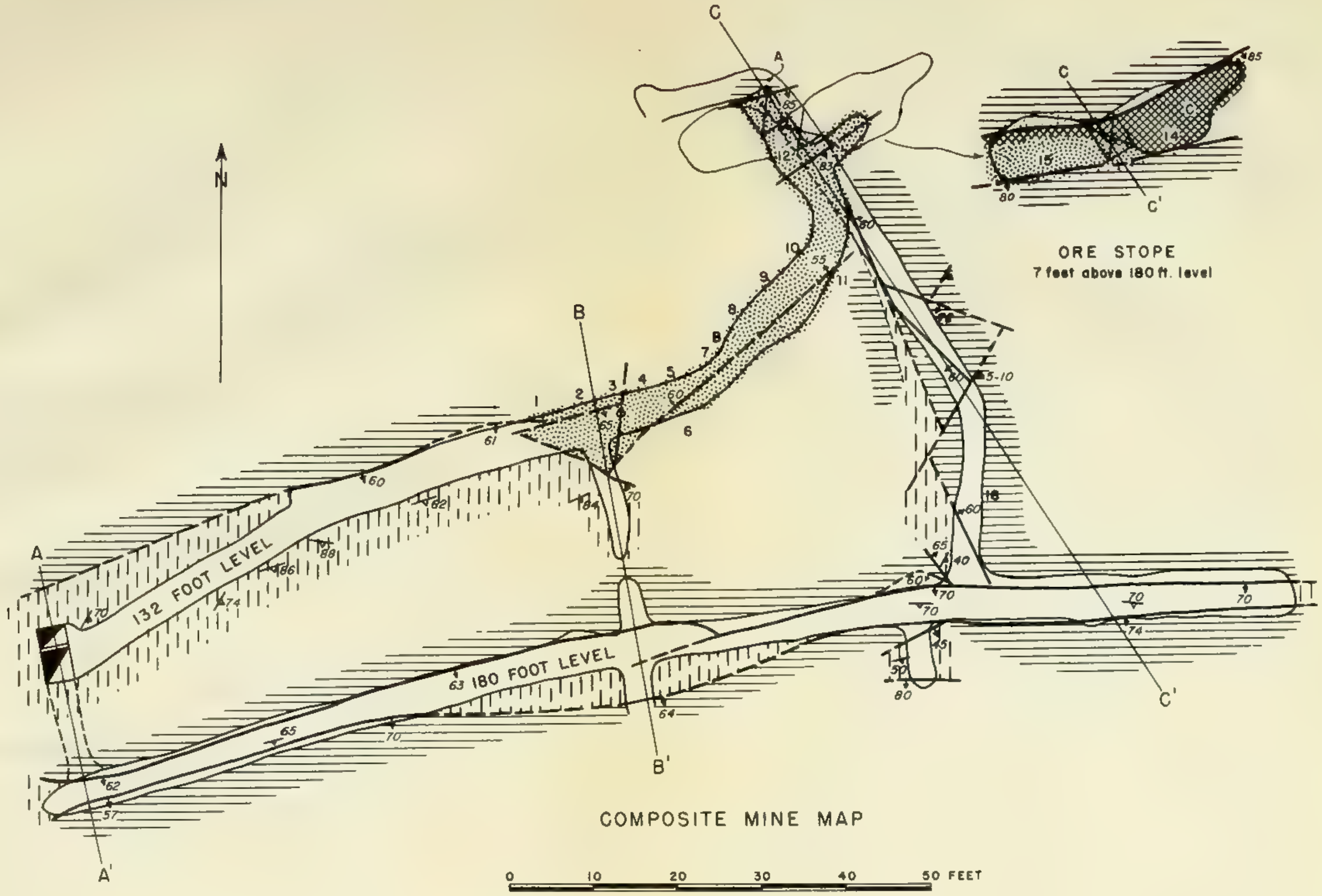
Because these faults were active both before and after the intrusion of the gabbro and are similar to breaks in the Friday mine that appear, in part, to control the mineralization, they merit consideration as a possible controlling factor in localization of ore, if further exploration or prospecting is planned for the area. Whether or not mineralization has occurred along them is not known, but the age and attitude of the faults are favorable.

FRIDAY NICKEL MINE

History and Development

The Friday nickel mine, which is owned by E. H. A. Andrews, 2716 84th Place, Inglewood, California; Raymond Jacobs, Julian, California; and associates, consists of one patented claim and the adjacent 80 acres to the north. The date of the first exploration on the gossan outcrop of the Friday mine is not known but was probably in the 1880's. Prior to 1918, the Friday Mining Company sank a shaft on the gossan outcrop, which contained a few dollars per ton in gold. This original shaft was abandoned, and the site now is covered by dump material; but a later shaft, located south of the old one, was accessible in 1944. Development work (pl. 4) consists of a 160-foot vertical shaft with a 55-degree incline extending from the bottom of the shaft to the 180-foot level. About 132 feet from the collar of the shaft a 105-foot drift runs to the northeast. At 65 feet from the shaft on the 132-foot level a 14-foot crosscut extends to the south, and at 105 feet a 17-foot crosscut extends to the northwest ending in a winze to the 180-foot level. The 180-foot level consists partly of a 144-foot drift running northeast. At the face of the drift a 48-degree incline follows the schist for a distance of 25 feet. About 67 feet from the incline that joins the shaft, short stub crosscuts extend north and south, and at 100 feet, a 10-foot crosscut extends to the south. A winding crosscut 105 feet from the incline runs northward 59 feet to the winze from the 132-foot level and extends 18 feet past it.

The shaft encountered the hanging wall of the schist at 112 feet and the footwall at 137 feet. The 132-foot level starts within schist and at 32 feet from the shaft reaches the schist footwall which follows the



COMPOSITE MINE MAP

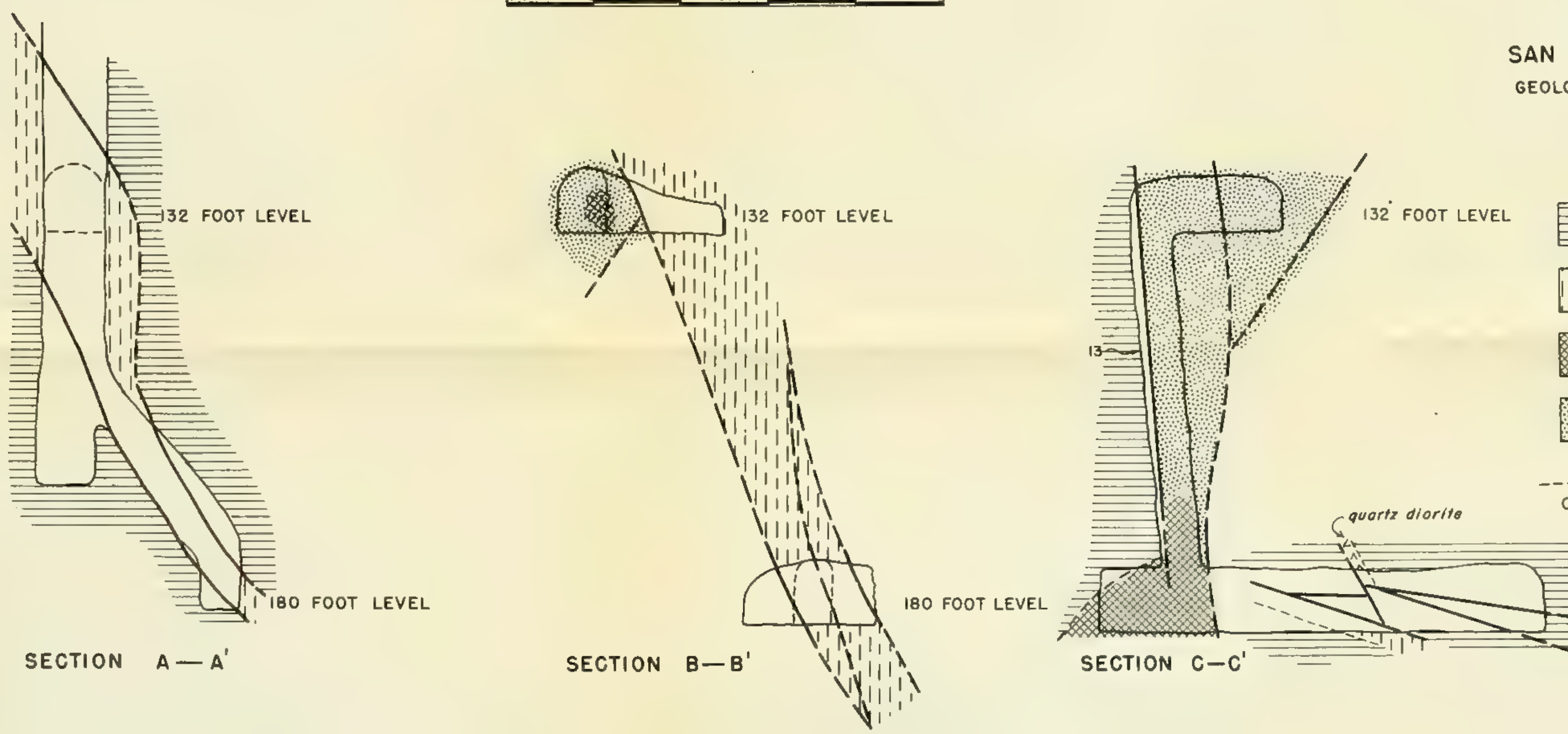
SAMPLE ASSAY DATA

Sample Number	Width feet	Nickel %	Gold oz.	Copper %	Cobalt %
1	4.2	2.42	tr		
2	7.9	3.08	tr.		
3	6.4	2.06	none		
4	4.7	1.91	0.03		
5	6.5	1.10	none		
6	6.3	1.44	none		
7	5.5	0.50	0.02		
8	6.0	0.36	tr		
9	7.1	0.31	none		
10	5.4	2.20	none		
11	4.1	5.70	tr.		
12	10.0	0.68	none		
13	4.4	2.12	none		
14	5.2	3.66	none		
15	8.7	2.37	tr		
16	2.7	0.37	none		
A	6.5	1.80		0.56	0.09
B	3.5	0.28		1.51	0.03
C	9.0	3.63		0.76	0.16

Samples 1 to 16 from a private report by C F Tolman and Z K Melcon
Samples A–C by U S Geological Survey

GEOLOGIC MAP AND SECTIONS
FRIDAY MINE
NEAR JULIAN
SAN DIEGO COUNTY, CALIFORNIA

GEOLOGY BY S C. CREASEY & R.M. HUTCHINSON
JUNE 1944

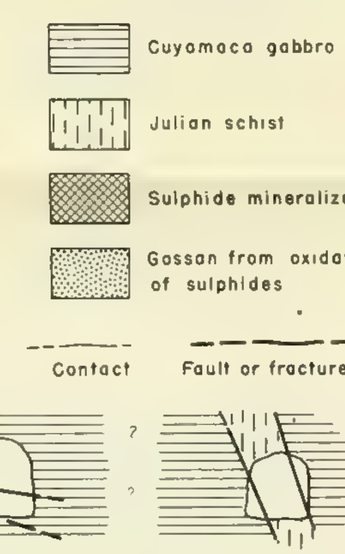


SECTION A—A'

SECTION B—B'

SECTION C—C'

EXPLANATION



drift for 33 feet and then bends sharply to the south. The drift from the shaft on the 180-foot level follows the schist inclusion for its entire length. Both the hanging wall and footwall contacts of the schist are faults from which splits or branches pass into the schist and gabbro. On the 132-foot level, mineralized rock is exposed for 55 feet along the drift, starting at a point 65 feet from the shaft and continuing to the winze to the 180-foot level; but on the 180-foot level it occurs only in the vicinity of the winze. A small tourmaline-bearing pegmatite dike, an irregular pegmatite mass, and one lamprophyre dike are exposed on the 180-foot level.

The present owners sank five diamond-drill holes on the property, but no assay records or logs are available. Two short holes were drilled from the workings of the Friday mine; one in the bottom of the shaft, one in the bottom of the winze, and two holes from the surface near the shaft. According to a reliable source, one of the surface holes was abandoned because of mechanical difficulties. No information is available on the other. Mr. E. H. A. Andrews reported the hole drilled in the bottom of the winze penetrated sulfide minerals averaging 2.26 percent nickel. He did not state the length or the attitude of the hole, but by necessity the hole must have been nearly vertical. According to Mr. Andrews, material from the hole drilled from the bottom of the shaft contained no nickel for the first 10 feet, but from 10 to 50 feet averaged 2.16 percent nickel.

Mineralization

The mineralized zone in the Friday mine is an irregular body striking about N. 75° E., and dipping steeply northward. It was formed by replacement of the Cuyamaca gabbro along fractures on the north side of an inclusion of schist that nearly parallels the ore in strike but dips about 60 degrees southward. The ore was observed in direct contact with the schist only on the 132-foot level.

Oxidation appears to be nearly complete from the surface to the 132-foot level, although soluble sulfates on the walls of that level suggest that some sulfides still may be present above it. Pockets of residual sulfides were observed on the 132-foot level near the winze to the 180-foot level and near the first crosscut to the south. These become larger and more abundant downward, but the maximum depth to which oxidation extends is unknown as some oxidation was observed in the ore stope at a depth of 173 feet. The mine does not reach the water table.

The true limits of the mineralized body can not be determined from the workings on the 132-foot level, which follows near the footwall of the mineralized zone for a little over 40 feet, then turns sharply and cuts across to the hanging wall. At the end of the drift, (section C-C′, plate 4), the width exposed is 22 feet, but only one wall is visible, hence the true width is somewhat greater. The ore is exposed along this level for 55 feet, which probably can be considered the true length of the ore shoot as the drift originally continued northeastward but was backfilled to its present termination. On the 180-foot level the ore body has been stoped, and the lagged crosscut extends through the backfill. However, in the ore stope, only 7 feet above the 180-foot level, the ore is from 6 to 9 feet wide, and both walls are exposed. The length of the body on this level is unknown, as the ore continues both east and west from the stope

which is only 32 feet long. Thus the ore body is wedge shaped in vertical section, tapering from a thickness of 22 feet or more on the 132-foot level to from 6 to 9 feet in the ore stope; it has a length of 55 feet on the 132-foot level and is somewhat longer than 32 feet on the 180-foot level. The body may widen below the 180-foot level following steep-dipping fractures.

The oxidized part of the ore body in the Friday mine is considerably lower in grade than the original sulfides. This may be due, in part at least, to leaching, which would produce the nickel-bearing sulfates observed on the walls of the 132-foot level. A grab sample of the sulfates assayed 11.75 percent iron, 0.10 percent copper, 0.15 percent cobalt, and 1.98 percent nickel. The mineralogical composition of the material is not known, but it is probably a mixture.

Observations made on the 132-foot level in the winze and in the ore stope seem to indicate that the ore is controlled partly by northeast-striking, high-angle fractures. The mineralized zone along the drift on the 132-foot level follows an indistinct mineralized fracture, and in the winze to the 180-foot level it follows a mineralized fracture which bounds the ore on the north as far down as the ore stope. On the 180-foot level west of the winze, the mineralized rock spreads to the north along the footwall of a fracture that dips 55 degrees and intersects the steep fracture in the winze (pl. 4, sec. C-C′). The south wall of the ore stope is bounded by a high-angle mineralized fracture. The strikes of these fractures nearly parallel the strike of the schist inclusion, but the dips are either steeper or in the opposite direction; consequently, they intersect the schist. Because of the difference in the physical properties of the schist and the mafic igneous rock, it seems reasonable to suppose that the fractures are deflected along the schist forming slips parallel to the foliation for at least a short distance, thereby creating a trap for mineralizing solutions.

Origin

Sulfide-bearing solutions, rising along the fractures, apparently ponded where the fractures intersected the schist. There the ponded solutions, reacting with the wallrock, formed an irregular replacement sulfide body in which the amount of replacement varies from place to place depending on such variable factors as intensity of fracturing, permeability, temperature, and pressure. The solutions were undoubtedly low in silica as shown by the absence of quartz and new silicates in the mineralized zone. Evidence is absent of volatiles other than a little water. However, weak hydrothermal alteration locally has produced chlorite and clay minerals along fractures and the contacts of the schist and the gabbro, and the fibrous green amphibole may have formed in this manner. Microscopic study of the wall rocks would be necessary before the degree of the alteration could be known fully. Apparently, the mineralizing solutions were fluid, high in sulfides, and comparatively low in water, but whether or not they could be called hydrothermal is debatable. Minerals that typically are formed in abundance by hydrothermal activity are absent.

Mineralogy

The sulfides from the mineralized zone in the Friday mine were identified by polished sections and x-ray pattern. The opaque minerals

present are: pyrrhotite, pentlandite, violarite, pyrite, chalcopyrite, and magnetite. Pyrrhotite is the most abundant mineral.

Pyrrhotite occurs as large crystals poikilitically enclosing other minerals. Violarite, identified optically and by x-ray pattern, is noticeably pink or violet compared to the brownish pyrrhotite. The pyrite present is a crystallized FeS_2 gel, and is finely divided showing a banded gel-like structure. It is very hard, a pale brassy yellow color, and occurs in vein-like structures in pyrrhotite. It is less stable chemically than ordinary pyrite, which may explain partly the rapid oxidation of the sulfides on exposure to air and water. The pyrite may be nickel-bearing.

Hydromagnesite, identified by x-ray, optical, and chemical methods, occurs as minute hollow spheres in the sulfides. Its major constituent is magnesium, and minor constituents are nickel and traces of copper, calcium, iron, and silica.

Reserves and Grade

The mineralized body in the Friday mine probably averages from 2.5 percent to 3.0 percent nickel, the actual grade depending on the extent and degree of oxidation in the unexposed parts of the mineralized zone. The average of all assays made from samples from oxidized and unoxidized localities is about 2.0 percent nickel. This figure can be considered safely as the minimum grade. Partly oxidized mineralized rock averages roughly 2.5 percent nickel, and unoxidized massive sulfides contain as much as 3.6 percent nickel.

The small number of copper assays precludes an accurate estimate of the average copper content. Copper is common in the massive sulfides as chalcopyrite and in the oxidized zone probably as a sulfate. From the assays available and the amount of copper observed in the underground workings, the copper content of the mineralized zone is estimated to be from 0.5 percent to 1.0 percent. As much as 0.15 percent cobalt is present in the massive sulfides and the soluble sulfates. The maps of the underground workings contain assays for the entire mineralized zone (pl. 4).

Assuming an average width of 15 feet and length of 55 feet and 9 cubic feet per ton of mineralized rock, approximately 5000 tons of indicated ore are between the back of the 132-foot and the floor of the 180-foot levels. Of this about one-sixth already has been mined. In addition, 90 tons of inferred ore per foot of depth may be assumed to a limited depth below the 180-foot level.

MINERALIZATION IN OTHER AREAS

In areas away from the Friday mine, sulfide bodies are indicated by gossans that contain relic structures like those in unaltered massive sulfides in the Friday mine, leaving little doubt that the gossans, in part, were derived from sulfides such as those found in the mine. Surface mapping located six gossan outcrops and five float areas, of which five of the outcrops and four of the float areas are within the Inspiration Point salient and one outcrop and one float area are within the Pine Hill salient. The gossan outcrops are exposed only by small prospect pits and trenches; in two localities they are exposed in more than one pit. Shallow trenching probably would expose gossans in

many of the float areas, which consist of weathered gossan boulders lying on the surface. The deep weathering conceivably could mask entirely the presence of gossans, as friable gossans could not be expected to crop out strongly where igneous rocks do not. The size of the gossan outcrops and the amount of gossan float may not indicate accurately the size of the area mineralized.

The nickel content of the gossan varies widely. Six gossan samples were assayed, three from Inspiration Point, two from Pine Hills, and one from the dump of the Friday mine. Table 1 gives the location and nickel content of the samples.

Table 1—Assays of gossan samples

Location	*Coordinates*	*Percent nickel*
Friday Mine	6000N-8000E	0.73
Inspiration Point	10090N-7240E	0.16
Inspiration Point	10000N-7070E	1.45
Inspiration Point	8900N-8080E	0.01
Pine Hills	SW¼NE¼ sec. 13	0.16
Pine Hills	SE¼SE¼ sec. 13	0.03

Chlorite-talc rocks occur locally in the same areas as the gossans, indicating some hydrothermal action.

GEOPHYSICAL INTERPRETATIONS

Geophysical studies made prior to the present investigation outlined several magnetic highs near the Friday mine and one at Inspiration Point. No ''highs,'' however, were indicated over known gossan outcrops at Inspiration Point or over the sulfide body in the mine, and no gossan float or outcrops were found in the area of magnetic highs near the mine. Because of this unusual relation between the location of the magnetic highs and known sulfide occurrences, possible explanations for the magnetic highs other than sulfide bodies were sought. At first the difference in magnetic susceptibility of the various phases of Cuyamaca gabbro suggested a possible explanation, as surface mapping showed the largest high near the Friday mine to be almost entirely within an area of the most basic rock type. However, B. S. Butler during his visit to the area discovered that the top soil contained an appreciable amount of dark red material identified by Charles Milton of the Survey laboratory as maghemite. Although the amount varies from place to place, maghemite was found in every place tested, not only in the Friday mine-Inspiration Point area but in numerous other places within the Cuyamaca gabbro. Maghemite is more abundant in the Friday mine-Inspiration Point area than most other places, but this is probably owing to the occurrence of more mafic rocks. In general, the areas of more mafic rocks overlain by a deep red soil contain the most maghemite. Samples of soil derived from the most mafic phase of the Cuyamaca gabbro near the Friday mine and at Inspiration Point contained 4 and 5 percent respectively of maghemite, and samples of decomposed rock from directly beneath the soil samples contained 5 and 1 percent maghemite.

Because magnetic methods lack depth control, slightly magnetic material near the surface might produce the same effect on the magnetometer as a more magnetic body at depth. Certainly, maghemite has a high magnetic susceptibility. It remains to be determined whether

sufficient quantities of it concentrated in the soil directly beneath a magnetometer conceivably could give readings comparable to those which have been obtained, and whether varying amounts of maghemite could explain the variation in the readings obtained from the different magnetometer stations.

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TIN DEPOSITS OF THE GORMAN DISTRICT, KERN COUNTY, CALIFORNIA*

By John H. Wiese ** and Lincoln R. Page **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

A number of small tin-bearing iron deposits were discovered in 1940, 1942, and 1943 on the south slope of the Tehachapi Range, in Kern County, California, about 6 miles northeast of the town of Gorman. The deposits are tactite bodies formed by the replacement of limestone along the boundaries of an intrusive body of granite. Cassiterite, the only tin-bearing mineral definitely recognized, is accompanied by magnetite, scheelite, pyrite, arsenopyrite, chalcopyrite, epidote, tourmaline, ludwigite, and amphibole, although all these minerals do not occur in each deposit.

The largest deposit, the Meeke, is for the most part a limonite gossan derived by weathering from pyrite, containing stringers, pods, and disseminated grains of cassiterite, generally associated with tourmaline. The other deposits contain higher proportions of magnetite and silicate minerals, and less limonite.

The only production has come from the Meeke mine, from which 5 tons of hand-sorted ore containing the equivalent of 1.93 tons of tin were shipped in 1944. At the end of 1944 all the properties were idle.

Reserves of ore in place in the district are estimated at 3,740 short tons containing 1.0 to 2.0 percent of tin, 3,450 tons containing 0.5 to 1.0 percent of tin, and 25,600 tons containing 0.1 to 0.3 percent of tin. Placer reserves total 800 cubic yards containing 15 to 30 pounds of tin per yard, 2,460 cubic yards containing 3 to 15 pounds of tin per yard, and 10,000 cubic yards containing 1.5 pounds of tin per yard.

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** Geologist, Geological Survey, United States Department of the Interior.

INTRODUCTION

The tin deposits of the Gorman district are about 6 miles northeast of Gorman, California, a town on the Los Angeles-Bakersfield highway (fig. 1). They are on the south flank of the west end of the Tehachapi Mountains, in T. 9 N., Rs. 17 and 18 W., near the southern boundary of Kern County. The distance by road from Gorman is 20 miles and from Lancaster, the nearest railroad point, about 33 miles. At Barnes Ranch, 10 miles east of Gorman, on the paved highway that leads to Lancaster, a graded dirt road branches off to the north and leads to the deposits. The dirt road has some steep grades and, although easily passable in dry weather, cannot be traveled for days at a time during the winter rains.

Tin was discovered in the Gorman district in 1940, when Willard Mallery identified cassiterite in the gravels at the head of Alamos Creek. In 1942 he found cassiterite at the Butler, Meeke, and Dunton iron prospects, and in 1943, in the vicinity of Crowbar Gulch. (See plate 5.)

Prior to the discovery of tin, the iron-bearing outcrops at the Upper Butler had been prospected by three shallow pits, those at the Lower

FIG. 1. Index map showing location of the Gorman tin district, Kern County, California.

Butler by three pits, and those at the Meeke by one pit 10 feet deep. In addition, some stripping had been done at the Meeke and Dunton deposits.

In November 1942, Mallery interested Dana Hogan, of the Hogan Petroleum Company, in these properties. With Hogan's backing, the surface was stripped at the Meeke, Lower Butler, and Upper Butler deposits. Later 9 pits, each 10 feet deep, were sunk at intervals of about 50 feet along the Meeke outcrops and two 50-foot inclined shafts with a total of 122 feet of drifts and crosscuts were dug.

In the summer of 1944 the United States Bureau of Mines explored the Meeke deposit by means of 11 diamond core-drill holes and did additional bulldozer work at the Meeke and Upper Butler deposits. At this time, Hogan and Mallery drilled one exploratory hole.

All the tin deposits, except the initial discovery, the Gray Eagle claim, are on La Liebre ranch, owned by the Tejon Ranch Company. Willard Mallery holds a permit to operate the Meeke and Butler properties, and he and Dana Hogan have a prospecting permit on the Crowbar Gulch and Dunton prospects. The Gray Eagle claim is on public land, and is held by Hogan and Mallery by right of location.

The tin production of the Gorman district (table 1) is limited to two shipments made from the Meeke deposits, consisting of high-grade nodules gathered from the surface and from the soil overlying the gossan.

Table 1. Tin production[a], Gorman district, Kern County, California

Date	Tons	Percent Sn	Impurities
May 1943	3.5	35.65	
December 1944	1.4	48.90	S-0.26, Pb-0.03, Sb-0.06, As-0.20, Bi-0.01, Cu-0.05, Zn-0.05.

[a] Sold to Metals Reserve Company, Fresno, California.

Previous Investigations

The tin deposits of the Gorman district have been examined by numerous members of the Geological Survey during the recent period of prospecting. The initial examination was made by D. M. Lemmon and P. C. Bateman in September 1942. In February 1943 the Meeke and Upper Butler deposits were mapped by Page, assisted by L. C. Pray and R. Porter, though field work was carried on at intervals from December 1942 to May 1943[1]. In October 1943 T. P. Thayer mapped the Crowbar Gulch deposits. Between June and September 1944 Wiese studied the district during the course of a joint Geological Survey-Bureau of Mines project at the Meeke and Upper Butler deposits. At this time the Meeke deposit was re-mapped (pl. 6) and a reconnaissance map (pl. 5) of the district was made using aerial photographs as a base.

Members of the Bureau of Mines visited and sampled the tin properties at various times from August 1942 to December 1944, and in the summer of 1944 a program of core drilling and bulldozer exploration was completed under the direction of Robert H. Bedford.

The writers are indebted to Mr. Willard Mallery for his willing cooperation and aid in the field work and for much information regarding the previous work done at these deposits. Mr. Dana Hogan kindly

[1] Page, Lincoln R., Meeke-Hogan tin prospect, Kern County, California: U. S. Geol. Survey Preliminary Map, 1943.

made available much valuable assay data. Miss Jewell Glass, of the Geological Survey, identified ludwigite, molybdenite, pargasite, vermiculite, and other minerals, and contributed to the report by her helpful discussion on the origin and nature of the deposits.

GENERAL GEOLOGY

The cassiterite-bearing deposits of the Gorman district are bodies of iron-rich tactite or gossan replacing recrystallized limestone at the margins of a granite intrusion (pl. 5). Erosion has exposed the granite in several places, and a northeast-trending, north-dipping series of limestone, hornfels, quartzite, and schist appears to form a thin shell, in most places only a few hundred feet thick, resting on the flat-roofed intrusive body. The outcrops of brecciated white dolomite shown on the map are probably erosional remnants of a thrust sheet which formerly extended over most of the area mapped. In the valley, terrace gravels cover the bedrock.

The meta-sedimentary rocks are unfossiliferous and their age is not known. They may belong to the Bean Canyon series, of Triassic and Jurassic age, which Simpson [2] has mapped in the adjacent Elizabeth Lake quadrangle. Most of the granitic intrusive rocks of this geologic province are believed to be of Jurassic age.

Rock Formations

Four main lithologic units were mapped in the district: (1) granite; (2) brecciated dolomite; (3) limestone, hornfels, quartzite, and schist; and (4) terrace gravels. On the detailed maps the different types of limestone, hornfels, and quartzite were mapped separately.

Brecciated Dolomite

Numerous patches of dolomite scattered over the district are believed to be erosional remnants of a thrust sheet. The dolomite is a white, fine-grained, brecciated rock with many intersecting calcite-filled fractures, which weathers to a characteristic rough surface. When freshly broken the rock has a fetid odor.

Limestone, Hornfels, Quartzite, and Schist

Medium- to coarse-grained, recrystallized limestones, interbedded with some hornfels, quartzite, and schist, crop out over much of the area mapped (pl. 5). These limestones are mainly blue to bluish-white in color, but in places they are bleached to light buff or white. At the margin of the granite the limestone has been altered to a white, fine-grained rock with a sugary texture, and only traces of bedding are indicated by a few streaks of hornfels. Near the iron deposits much of the limestone has a brownish cast, caused by fine-grained iron oxide along the cleavage planes and crystal boundaries of the calcite.

Thin layers of hornfels occur throughout the limestone, and some members at least 100 feet thick are predominantly hornfels. The hornfels is a finely laminated, greenish rock made up mostly of garnet, zoisite, and epidote. It is easily weathered and crops out only in a few places, although small fragments persist as float over long distances.

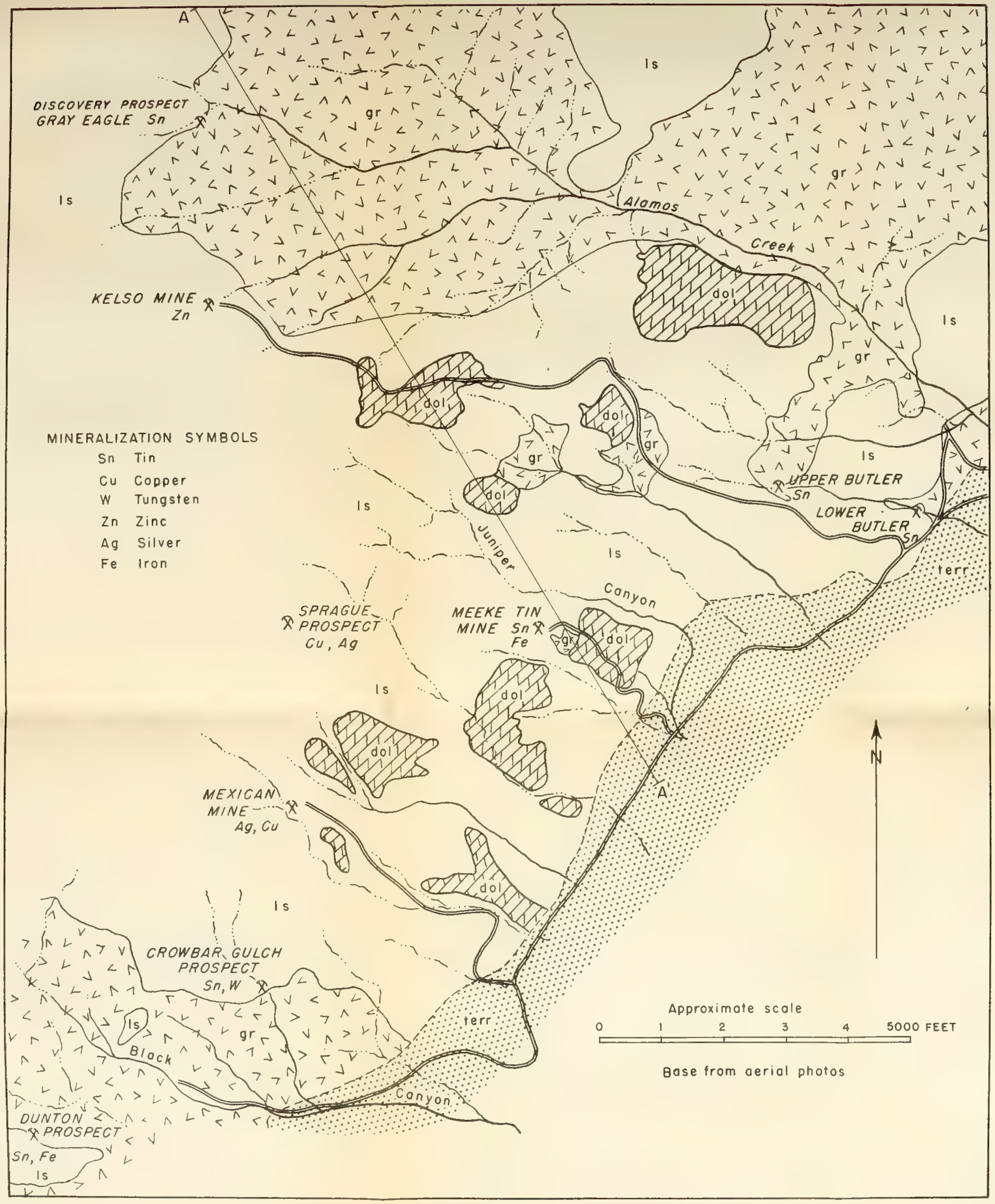
[2] Simpson, E. C. Geology and mineral deposits of the Elizabeth Lake quadrangle, Calif.: California Div. Mines Rept. 30, pp. 371-415, 1934.

GEOLOGIC MAP AND SECTION
OF THE

GORMAN TIN DISTRICT

KERN COUNTY, CALIFORNIA

GEOLOGY BY John H. Wiese
1944



LEGEND

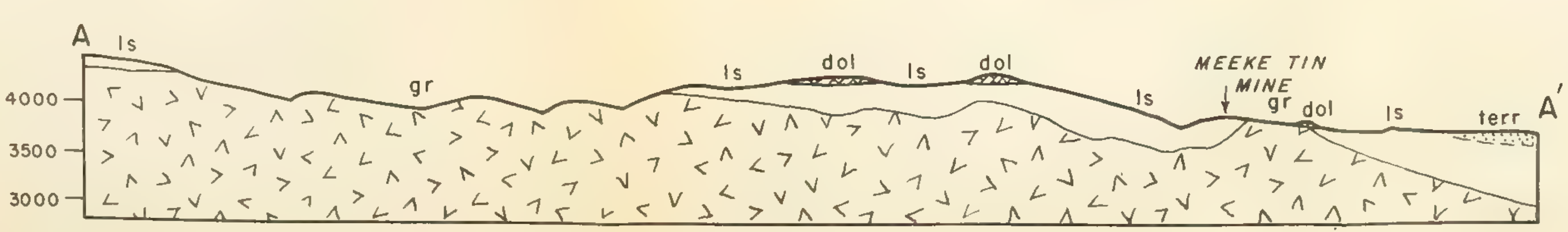
terr — Terrace deposits.

dol — Brecciated dolomite.

ls — Limestone, hornfels and schist.

gr — Granite

Mine or prospect.



Thin layers of fine-grained white to green quartzite occur in many places in the limestone and are even more common in the hornfels members. At the Meeke tin mine one 20-foot layer of quartzite and interbedded hornfels served as a horizon marker in mapping.

In Juniper Canyon, northeast of the Meeke mine, there are small outcrops of a fine-grained, greenish schistose rock whose relation to the limestone is not known.

Granite

Granite probably underlies the entire area shown on plate 5, but it is exposed only along Black Canyon and Alamos Creek, and as isolated patches north and south of Juniper Canyon. The contact between granite and limestone is generally poorly exposed, for leaching and slumping of the limestone at the contact is common. In most places the contact dips gently between 5° and 40°. No fault contacts between granite and limestone were observed, although at the Upper Butler and Meeke prospects the granite appears to have been intruded along pre-existing faults.

Most of the granite is a light-colored, medium- to coarse-grained rock consisting of approximately equal amounts of quartz and potash feldspar in a graphic intergrowth associated with perthite and antiperthite. Muscovite, the most common accessory mineral, is associated with lesser quantities of biotite, hornblende, and magnetite. Near the contacts the granite is much finer grained, and has an almost aplitic texture. In places there are coarser pegmatitic streaks of quartz and feldspar in an aplitic matrix. The coarser-grained parts of the granite are deeply weathered and furnish fewer good exposures than the finer-grained facies.

Structure

The Gorman tin district is a few miles east of the San Andreas fault and between two branches of the Garlock fault. These are two of the major structural features of southern California, and as a result the structure of the tin district is complicated by many minor faults and associated folds. No attempt has been made to work out the detailed structure of the district as a whole (pl. 5), though a major thrust fault which underlies the brecciated dolomite has been mapped. The faults and folds shown on detailed maps, such as plate 6, indicate the structural complexity of the entire district.

The major thrust fault strikes northeast and dips 5° to 40° SE. Outcrops of brecciated dolomite (pl. 5) are the only remnants of the overthrust block. Small granite boulders found in the soil at the Meeke tin deposit, uphill from any known granite outcrops, indicate that the thrust was post-granite in age and that the overriding block moved northwestward.

In the area immediately adjacent to the Meeke deposit (pl. 6) there appear to be three sets of faults. One set, which includes the East fault, strikes northwest and dips steeply. The second set, also steeply dipping, strikes west-northwest. The third set, which includes the North fault, strikes east-northeast and dips from 45° to 90° SE. Minor folding, probably the result of drag, is commonly present adjacent to these faults, although the rocks may have been folded prior to faulting.

MINERAL DEPOSITS

Although the tin deposits of the Gorman district are similar in origin, the individual deposits differ widely in size, shape, mineral composition, and degree of alteration. The two largest, the Meeke and Upper Butler, probably contained a large proportion of sulfides and have been weathered to limonitic gossans; the smaller deposits are relatively unweathered. In the primary ore, cassiterite occurs with scheelite, powellite, pyrite, chalcopyrite, arsenopyrite, molybdenite, magnetite, epidote, tourmaline, ludwigite, amphibole, garnet, phlogopite, calcite, and quartz, though not all of these minerals occur in each deposit. As a result of secondary alteration the sulfides have been altered to hydrated iron oxides associated with malachite, chrysocolla, jarosite, gypsum, chalcedony, opal, cuprite, native copper, and clay minerals. The magnetite is in part altered to hematite and the amphibole to chlorite.

At the Meeke and Upper Butler prospects the cassiterite is in limonitic gossan, indicating that the original ore contained a large proportion of sulfides, though only a few relict nodules of massive pyrite remain. The Lower Butler and Dunton prospects are primarily magnetite-rich tactite deposits with minor quantities of sulfides. The Crowbar Gulch and Gray Eagle deposits are tactite characterized by fibrous to radial amphibole with minor magnetite and ludwigite. Apparently the cassiterite is not as closely associated with the magnetite as with the sulfide and silicate minerals.

The largest deposits are less than 250 feet in length and 40 feet in width, and to date none have been proved to extend down dip more than 150 feet. Most are measured in tens of feet and few are large enough to be worth consideration as an economic operation. All the deposits are very irregular in shape and unpredictable in depth.

The proportion of cassiterite is quite variable both from deposit to deposit and from place to place within individual deposits, resulting in a wide variation in the assay results. At the Meeke, although specimens weighing several pounds assayed more than 50 percent tin, the main ore shoot contains only 1.5 to 2.0 percent tin and the average grade of most of the tin-bearing rock is 0.1 to 0.5 percent tin.

The occurrence of tin in limestone replacement deposits has also been noted in the Cima district in San Bernardino County, California. Both there and at Gorman cassiterite is associated with scheelite and sulfide minerals in deposits with contact-metamorphic relationships. At the Meeke deposit the relict sulfide masses clearly indicate that cassiterite was more closely related in the original ore to the sulfides than to the magnetite, and it is evident that the gossan was developed by the weathering of sulfide minerals. The association of cassiterite with amphibole, ludwigite, and tourmaline was observed only in the Gorman area, not at Cima.

MINES AND PROSPECTS

Six groups of tin-bearing deposits have been recognized in the Gorman district. Only one, the Meeke deposit, has produced tin ore of commercial grade. Five others, the Dunton, Crowbar Gulch, Lower Butler, Upper Butler, and Gray Eagle deposits have been prospected only to shallow depths. At other places along the margin of the granite,

small, scattered pods and lenses of magnetite-rich tactite have been found, and additional prospecting might discover other tin-bearing bodies.

Meeke Tin Mine

The Meeke tin deposit is at an altitude of about 3,900 feet, on a flat spur halfway between Alamos Creek and Black Canyon, about half a mile from the edge of the valley floor (pl. 5). It may be reached from Barnes ranch by dirt road along the edge of the valley to Juniper Creek and thence over a steep grade to the spur. A permanent spring, 1,000 feet south of the mine and about 250 feet lower, has a flow sufficient to supply a small mill or mining operations.

Mr. Willard Mallery discovered tin in the limonitic gossan at the Meeke deposit in the spring of 1942.[3] Some years before, the deposit had been prospected for gold and iron by means of a 10-foot pit and a small bulldozer trench. In 1942 and 1943 Mallery and Hogan explored the property by bulldozing and by sinking 9 pits, each 10 feet deep, and two inclined shafts, known as the East and West shafts, each about 50 feet deep. At the West shaft, 105 feet of drifts and crosscuts were made to the north from the 23-foot level (fig. 2) and an 18-foot crosscut was driven south from the bottom of the shaft. A crosscut 23 feet long curves southeast from the bottom of the East shaft.

In June 1944 the Bureau of Mines carried out an extensive stripping program and removed most of the remaining overburden from the two gossan areas. In July and August the Bureau of Mines, in cooperation with the Geological Survey explored the ore bodies at depth with 1,000 feet of core drilling, and at the conclusion of that project, Hogan and Mallery drilled another hole to a depth of 84 feet.

In May 1944, 3½ tons of sorted ore containing 35.65 percent of metallic tin was trucked to the Metals Reserve Company stockpile in Fresno, California. The shipment consisted entirely of high-grade residual boulders from the soil near the West shaft. In December, Mallery made another shipment of 2,770 pounds of sorted ore to the Metals Reserve Company. A small part of this was from near the West shaft, but most of it came from a layer of high-grade nodules in the soil near pit 8 (pl. 6). This shipment contained 48.90 percent of tin (table 1). At the end of 1944, about 3 tons of sorted ore, estimated to contain 10 to 20 percent of tin, was stockpiled.

Geology and Structure. The Meeke tin deposit is in bleached, recrystallized limestone about 200 feet from the nearest outcrop of granite (pl. 6), but as bleached limestone appears to occur only near granite contacts in this district, it seems likely that granite underlies the deposit at a shallow depth.

The sedimentary rocks are cut by at least four main faults and many smaller ones. The East fault, the major structure, dips 70° to the east and can be traced between limestone and hornfels for several hundred feet north of the mapped area. South of the mapped area it passes under the brecciated dolomite and the thrust fault. The block west of this normal fault has moved relatively northward, perhaps as much as 1,000 feet.

[3] Mallery, Willard, Tin in California: The Dana Magazine (Los Angeles, Calif.), Part I, vol. 5, no. 1, pp. 8-11 and 18-20; Part II, vol. 5, no. 4, pp. 6-8, 1944.

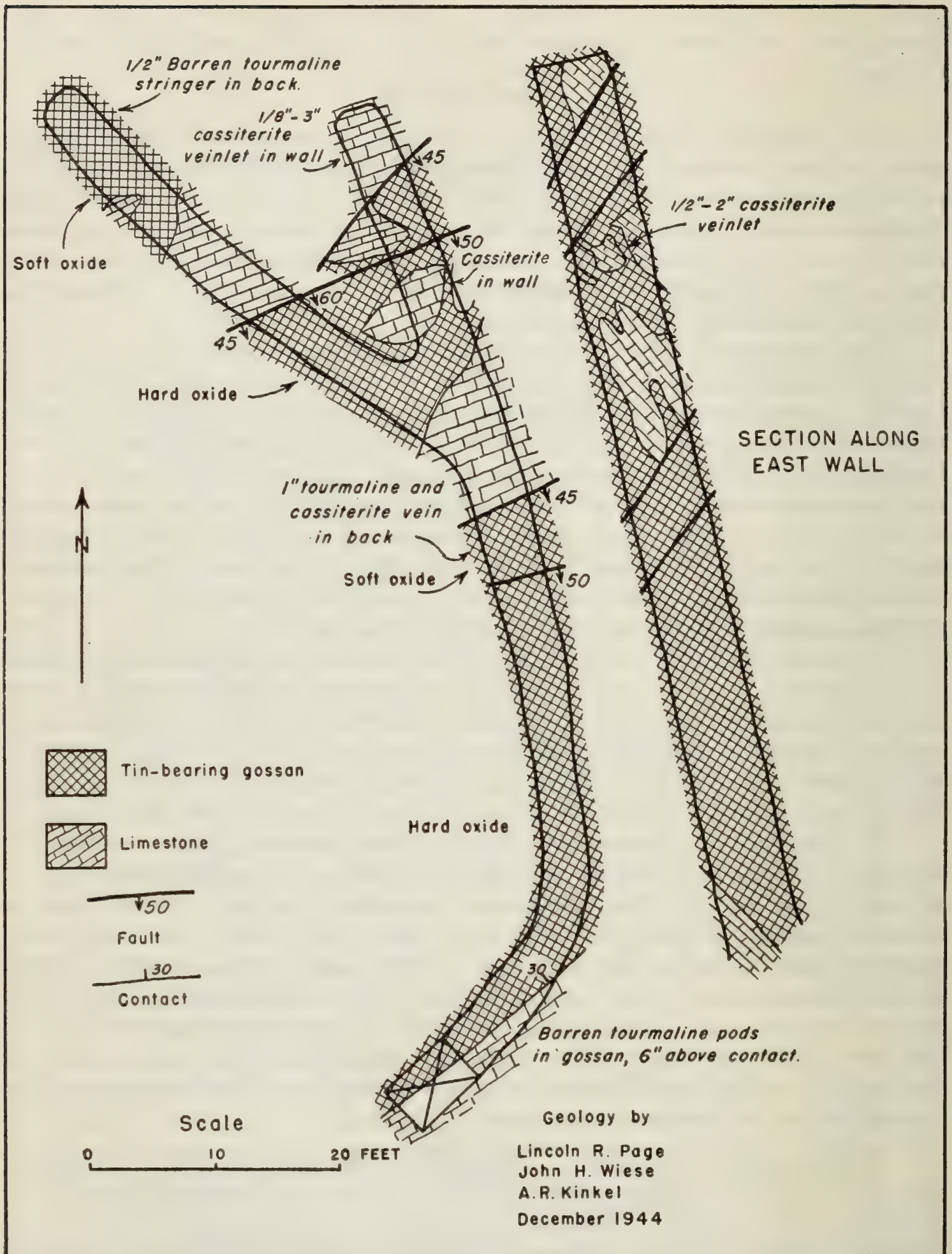
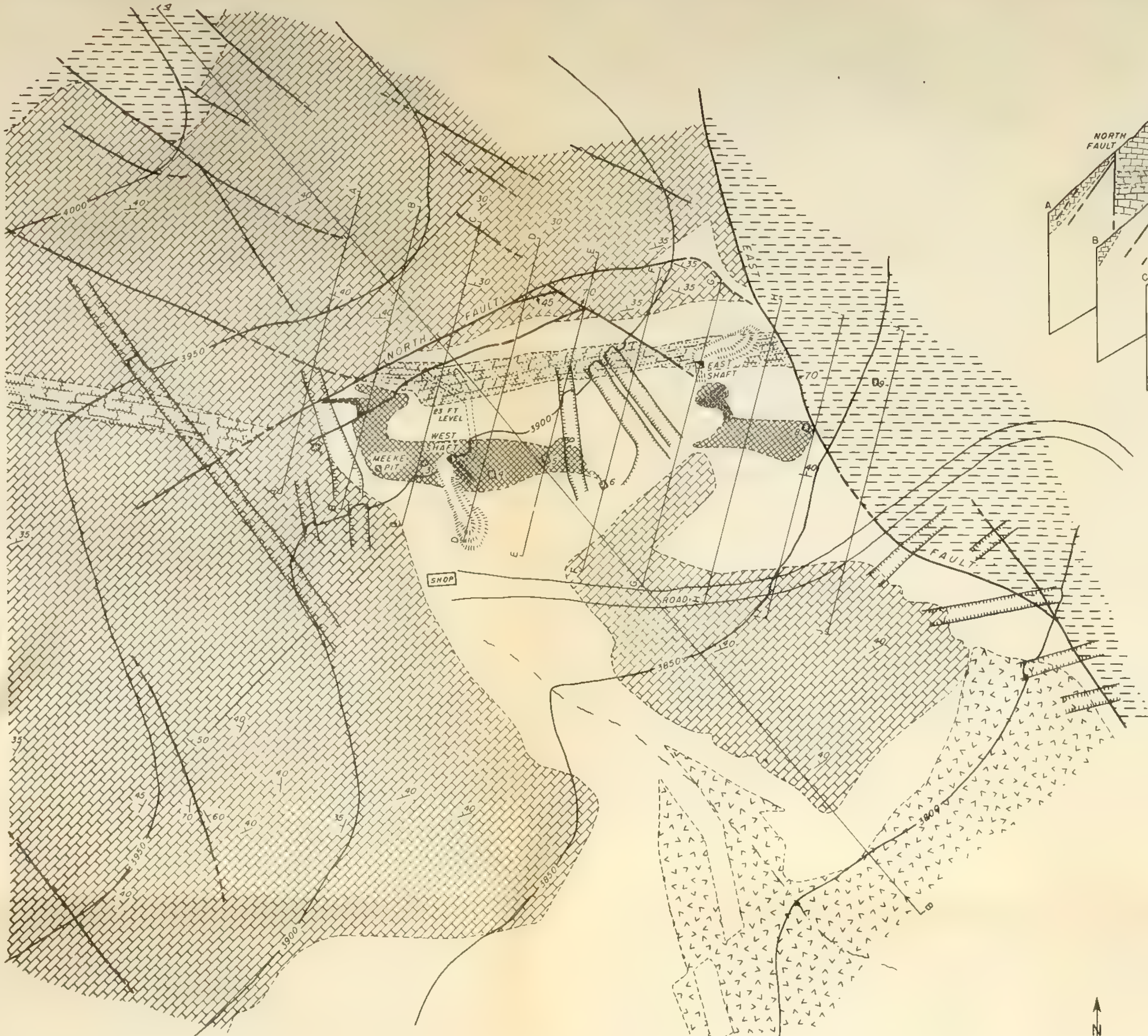
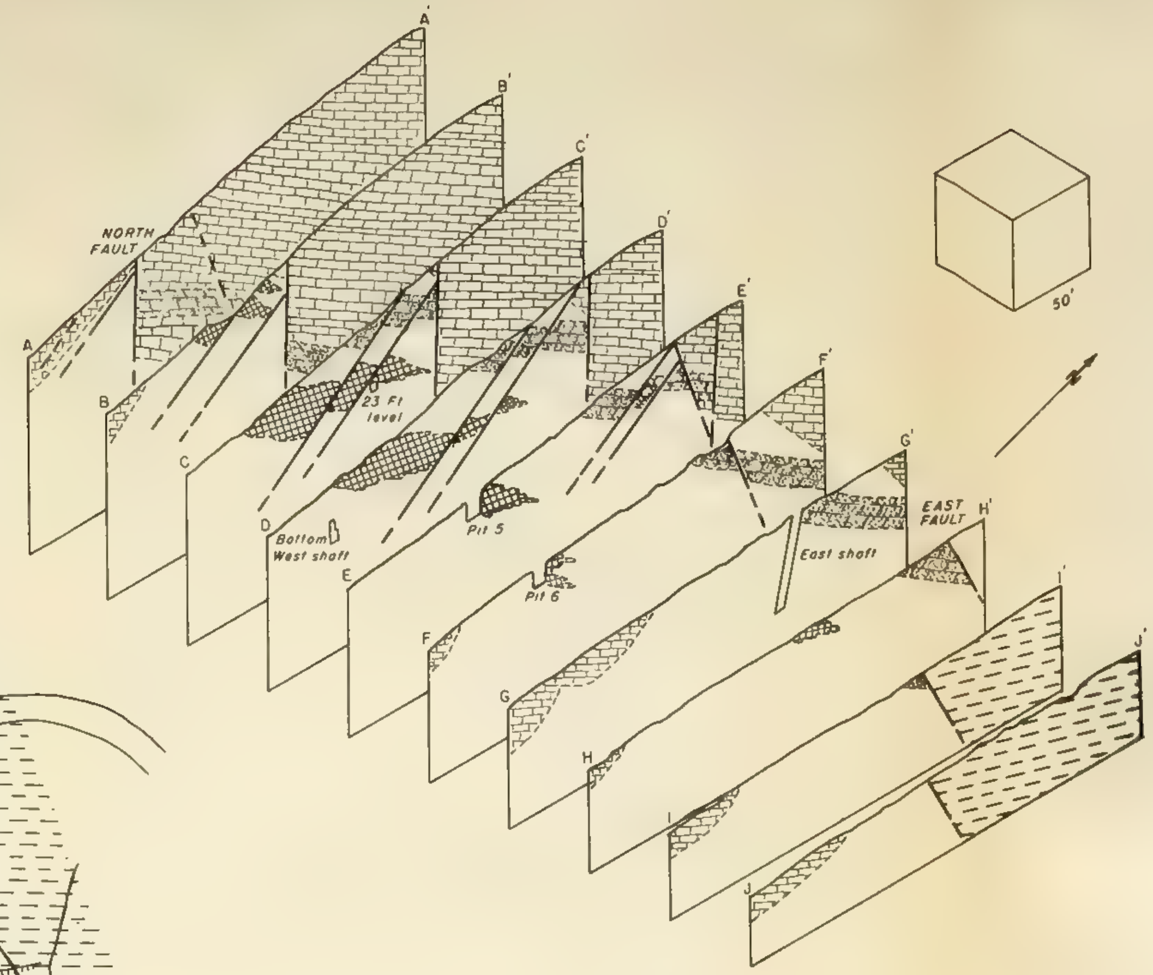


FIG. 2. Plan and section, 23-foot level, Meeke tin mine.

A second important fault, the North fault, strikes N. 60° E. and dips nearly vertically. The north block has moved about 120 feet southwestward relative to the south block. South of the North fault there are two smaller faults and many small slips which also strike N. 60° E. and dip 45° or more to the southeast. Where these faults offset the ore body (pl. 6), slickensided surfaces show that the latest movement was essentially horizontal.



GEOLOGIC MAP



ISOMETRIC DIAGRAM

GEOLOGIC MAP, SECTION, AND ISOMETRIC DIAGRAM OF THE

MEEKE TIN DEPOSIT

KERN COUNTY, CALIFORNIA

Geology by John H. Wiese
1944

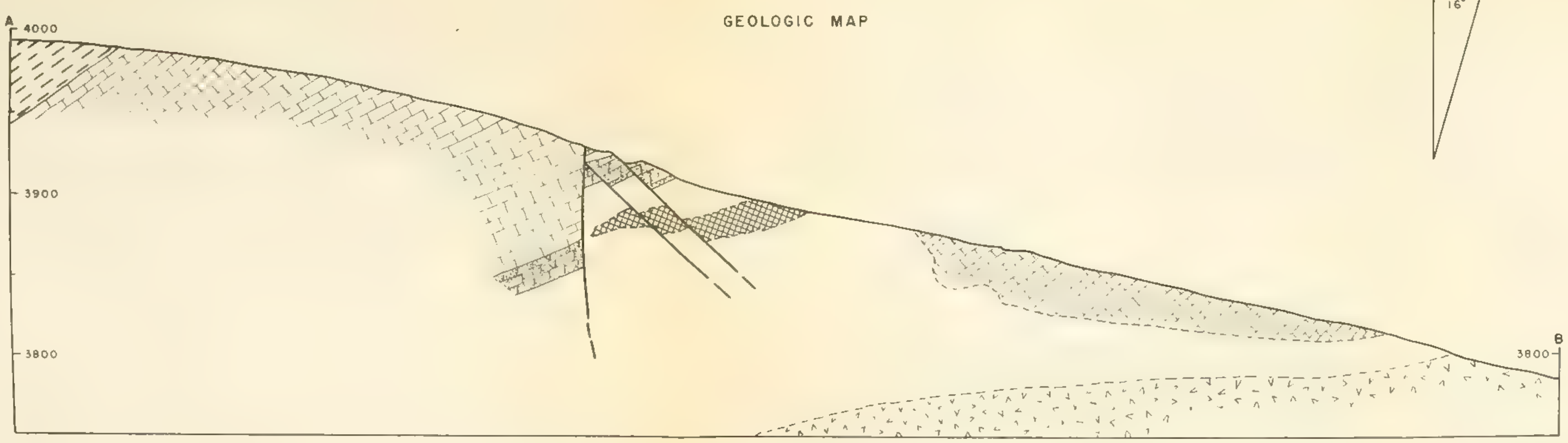
EXPLANATION

- Cassiterite bearing gossan
- Magnetite
- Granite
- Bleached limestone
- Blue limestone
- Quartzite
- Hornfels
- Fault
- Contact
- Bedding
- Trench
- Pit
- Dump
- Inclined shaft

SCALE

0 50 100 200 FEET

Contour interval 50 feet Datum approximate sea level



SECTION A—B

Throughout the limestone there is a strong set of joints that strike east, and dip 70°-80° S. Another series of joints and small faults strikes N. 50° W. and dips steeply. These fractures are best exposed northwest of the deposit, where they offset the contact between the limestone and the overlying hornfels.

The flat-lying dolomite thrust sheet (pl. 5) probably extended above the deposit only a few feet above the present land surface. Rounded pebbles of granite were found at several localities between pit 5 and the East fault (pl. 6) in crevices in the bedrock beneath several feet of soil. As no granite is known to crop out on the slopes above, these pebbles are regarded as remnants of the breccia at the sole of the thrust sheet. If this interpretation is valid, the thrust sheet must have moved relatively northward.

Mineralogy. Cassiterite, the ore mineral, occurs in dark brown grains and crystals as much as half an inch in diameter, but most of the grains are very small and cannot be seen readily in the gossan because they are obscured by iron oxides. The cassiterite grains form thin stringers and clusters in parts of the gossan and limestone, and fine grains or crystals can be found disseminated through most of the gossan. At the surface of the gossan boulders of cherty iron oxide, as much as 5 feet in diameter, contained irregular streaks and pods of granular cassiterite. This residual material was hand-cobbed and shipped. Underground, small veinlets and pods of granular cassiterite with fine-grained greenish tourmaline occur in essentially barren clay, gossan, and limestone (fig. 2). Specimens collected from these veinlets have assayed as much as 50 percent tin.

In thin sections of unoxidized material the cassiterite shows remarkably perfect color zoning and commonly appears as euhedral twinned crystals replacing calcite, associated with magnetite, pyrite, epidote, and garnet. The iron oxides of the gossan ore are later than these minerals and are accompanied by secondary cherty silica and calcite. Concentrates of samples contain occasional grains of chalcopyrite, arsenopyrite, and galena. Scheelite and powellite are associated with the cassiterite ores at pits 8 and 2.

Cassiterite may occur in any of the varieties of iron oxide making up the gossan, which range from soft, clayey, friable varieties to hard clinkery material, that may be light to dark yellow, brown, red, or purplish red in color. Irregular masses of magnetite and epidote, containing little cassiterite, if any, occur in the limestone and hornfels near pit 7 and northwest of pit 2. The magnetite shows little evidence of alteration, though hematite forms thin films along fractures.

Some of the tin ore in the north wall of the bulldozer cut about 20 feet northeast of pit 2 consists of dark brown grains of cassiterite in a soft, greenish micaceous mass made up principally of a potassium-bearing vermiculite. Miss Jewell Glass of the Geological Survey who studied samples of this material, says, "The vermiculite is derived from a pale green chlorite; the chlorite in part at least is derived from a blue-green, potassium-bearing amphibole, probably pargasite. Other minerals present are calcite (secondary), strontianite, zoisite, magnetite, hematite, limonite, and apatite. The rock is extremely altered, apparently as a result of the action of hydrothermal solutions in a contact-metamorphic zone." Material similar to this but containing a larger

Table 2. Results of diamond drilling by the Bureau of Mines at the Meeke tin deposit

Hole number	Inclination	Formations, intervals in feet				Percent tin in gossan			Remarks
		Limestone	Hornfels	Quartzite	Gossan	Core	Sludge	Weighted	
1	55°	0-84			None				0-10 feet rubble with some gossan fragments.
2	60°	0-99			None				Brecciated limestone 100-116 feet.
3	45°	0-116	116-124		None				A few thin veinlets of magnetite between 50 and 60 feet.
4	60°	0-142			None				
5	50°	0-81			None				
6	60°	40-66		0-13.5	13.5-18	0.08	0.06	0.06	Gossan soft and porous, variegated.
					18-26	0.02	0.05	0.05	Traces of cassiterite in pannings of sludge.
					26-33	0.02	0.02	0.02	A few irregularly replaced limestone fragments.
					33-40	0.03	0.03	0.03	Hard jaspery limonite, cellular at base.
7	60°	30.5-45		0-12	12-17	9.10	1.82	2.33	Variegated and micaceous gossan.
					17-22	1.81	2.63	2.47	Mottled soft gossan, harder toward bottom.
					22-33.5	0.75	1.46	1.37	Mottled soft gossan.
8	60°	25-78		8-25	None				No core 0-8, probably limestone.
9	60°	0-8, 25-52		8-25	52-56	0.06	0.39		Hard jaspery limonite, upper 3 inches cellular.
		59-81			56-59	0.17	0.25		Soft gossan with micaceous streaks.
10	90°	0-8, 18-54, 66-88		8-18	54-59	6.13			Hard limonite, sludge 52-59 had 1.36 percent of Sn.
					59-62.5	5.10	4.59		Soft porous limonite, fine-grained cassiterite.
					62.5-66	0.06	1.12		Sludge possibly salted from above.
11	90°	0-14, 30-59, 59.5-112		14-30	59.5-60	0.04	0.03		Interval 59-63 assayed; gossan from 59-59.5 only.
H-1 [a]	90°	0-10, 25-62.5, 64-84		10-25	62.5-64	Not assayed			No cassiterite observed in core or pannings of sludge. Only 5 inches of gossan core recovered.

[a] Hole drilled by Hogan and Mallery.

proportion of limonite was found in drill holes 7 and 10 and in the underground workings on the 23-foot level.

A qualitative spectrographic examination of a composite sample of gossan ore from the Meeke deposit, made by the Smith-Emery Company for the Geological Survey, gave the following results:

Major constituents:—Calcium, iron
Intermediate constituents:—Silicon, zinc
Minor constituents:—(amounts approximate)

1%	Al
0.5%	Sn, Mg
0.1%	Cu, K, As, Ba
0.05%	Sr, Ti, Mn, Na
0.01%	W, B, Sb, Pb, Mo
0.005%	In, Cr, V, Be
Trace	Cd, Ag

No zinc minerals were recognized at the deposit; they were probably masked by the iron oxides and clay. Only a small amount of zinc was reported in the ore shipments (table 1).

Size and Grade of the Tin Deposits. The two bodies of tin-bearing gossan on the Meeke property are referred to as the West and East gossan. In general, cassiterite-bearing rock is limited to these gossan areas, though cassiterite was observed in limestone at pit 8 and also on the 23-foot level of the mine (fig. 2). However, not all parts of the gossan carry appreciable quantities of cassiterite. The tin ore appears to occur in small streaks, pods, or masses scattered through gossan that contains little cassiterite.

On the surface, the West gossan is a hook-shaped body which extends about 200 feet westward from pit 6 and then about 75 feet northward to the North fault. It has a maximum exposed width of 40 feet, and lenses out at either end. The initial shape of the primary sulfide ore body was probably very irregular in detail, and this was later complicated by the solution and collapse of limestone, migration of iron oxides, and faulting. The gossan dips gently northward and diamond drilling has indicated that it lenses out about 150 feet down the dip. The base of the gossan is exposed, at a depth of 10 feet, in pits 2, 4, 5, 6, and in the Meeke pit. The West shaft passes through gossan containing high-grade streaks and pods of cassiterite and intersects limestone at 23 feet. The drift on the 23-foot level follows the base of the gossan eastward and then turns northward across gossan and limestone (fig. 2). These exposures and the results of diamond drilling indicate that the maximum thickness of the gossan is about 25 feet.

One ore shoot of appreciable size was partially outlined by diamond drilling. This ore shoot is in a northeast-pitching synclinal fold at the extreme west end of the West gossan. It is probably less than 30 feet in length at the surface and may average about 8 feet in thickness for 120 feet down the dip. Pit 2 is at the upper end of this ore shoot and drill holes Nos. 7 and 10 cut it at depth (table 2). Drill hole 7 passed through 21.5 feet and hole 10 cut 11 feet of ore. Drill holes 9 and 6 may delimit the south edge and drill holes 11 and H-1 appear to approximate the north edge of the ore shoot. There has been no systematic sampling of surface exposures to outline this ore body and to determine its grade accurately. One sample (LRP-27H-43, table 3) representing the upper 4 feet of ore shoot, contained 0.8 percent of tin, according to

Table 3. Assay data, Meeke tin deposit

Location of samples	Geological Survey: Sample number	Geological Survey: Type of sample	Geological Survey: Length of sample (feet)	Geological Survey: Character of material	Geological Survey: Per-cent tin	Bureau of Mines: Type of sample	Bureau of Mines: Length of sample (feet)	Bureau of Mines: Character of material	Bureau of Mines: Per-cent tin
Pit 2									
Northeast side, above limestone.	LRP- 4H-43	Channel, right angles to contact.	3.5	Hard and soft gossan.	0.35 [a]	-----	-----	-----	0.04
Northeast side, above LRP-4H-43 ([c])	LRP- 5H-43	Vertical channel	2.5	Soft gossan	1.03 [a]	-----	-----	-----	-----
Bulldozer trench									
Upper part of ore shoot. North side bulldozer cut 30 ft. west of collar, drill hole 7. ([d])	LRP-27H-43	Vertical channel	5.0	-----	0.8 [b]	-----	-----	-----	-----
Pit 3									
Top of northwest side	LRP- 9H-43	Vertical channel	2.5	Surface debris	4.99	-----	-----	-----	0.04
Northeast side, below surface debris.	LRP- 8H-43	Vertical channel	5.0	Soft gossan	0.06 [b] >0.01	-----	-----	-----	0.03
Pit 4									
Northeast side, from surface downward.	LRP-11H-43	Vertical channel	5.0	Hard and soft gossan.	0.02	-----	-----	-----	0.04
Northeast side, bottom upward.	LRP-10H-43	Vertical channel	5.0	Hard and soft gossan.	0.5	-----	-----	-----	-----
Pit 5									
Southeast side, between surface debris and limestone.	LRP-15H-43	Vertical channel	6.0	Hard and soft gossan.	0.09 [a]	-----	-----	-----	0.01
Pit 6									
Northwest side, above limestone.	LRP-17H-43	Vertical channel	5.0	Hard and soft gossan.	0.01 [b]	-----	-----	-----	0.03
Pit 7									
Southeast side, above limestone.	LRP-18H-43	Vertical channel	5.0	Soft gossan	0.03 [b]	-----	-----	-----	0.56
Southeast side, above LRP-18H-43	LRP-19H-43	Vertical channel	3.0	Magnetite	0.03 [b]	-----	-----	-----	-----

Pit 8									
Southeast corner pit	LRP-23H-43	Channel across gossan	1.6	Hard gossan	$\gg$ 1.0[b]	----------	----------	----------	----------
Southeast side, above LRP-23H-43.	LRP-22H-43	Channel across limestone beds.	3.0	Limestone and stringers of cassiterite.	2.43	----------	----------	----------	----------
Northwest side, surface downward.	LRP-25H-43	Vertical channel	3.0	Hard gossan	0.05[b]	----------	----------	----------	----------
Northwest side, below LRP-25H-43.	LRP-24H-43	Inclined channel	1.0	Soft yellow gossan.	.08[b]	----------	----------	----------	----------
		Joint Geological Survey-Bureau of Mines sampling—west wall, cross-cut and drift, 23-ft. level							
North wall drift, 5 feet east of shaft.	541	Vertical channel	5.0	Hard gossan	$\ll$0.01[b]	Vertical channel	5.0	Hard gossan	0.02
Back, 13 feet east of shaft	542	Horizontal channel	3.0	Hard gossan	0.01[b]	Horizontal channel	3.0	Hard gossan	0.02
13-18 feet from shaft	529	Horizontal channel	5.0	Hard gossan	0.02[b]	Horizontal channel	5.0	Hard gossan	0.02
18-22 feet from shaft	530	Horizontal channel	5.0	Hard gossan	0.03[b]	Horizontal channel	5.0	Hard gossan	0.03
22-27 feet from shaft	531	Horizontal channel	5.0	Hard gossan	0.01[b]	Horizontal channel	5.0	Hard gossan	0.08
27-32 feet from shaft	532	Horizontal channel	5.0	Hard gossan	<0.01[b]	Horizontal channel	5.0	Hard gossan	0.06
32-37 feet from shaft	533	Horizontal channel	5.0	Hard gossan	0.01[b]	Horizontal channel	5.0	Hard gossan	0.06
37-42 feet from shaft	534	Horizontal channel	5.0	Hard and soft gossan.	0.02[b]	Horizontal channel	5.0	Hard and soft gossan	0.32
					0.018	Horizontal channel	5.0	Soft gossan	0.07
42-47 feet from shaft	535	Horizontal channel	5.0	Soft gossan	0.01[b]	Horizontal channel	5.0	Soft gossan	0.06
47-52 feet from shaft	536	Horizontal channel	5.0	Soft gossan	<0.01[b]	Horizontal channel	5.0	Soft gossan	0.01
52-57 feet from shaft	537	Horizontal channel	5.0	Soft gossan	<0.01[b]	Horizontal channel	5.0	Soft gossan	0.05
57-62 feet from shaft	538	Horizontal channel	5.0	Soft gossan	0.01[b]	Horizontal channel	5.0	Soft gossan	0.02
62-67 feet from shaft	539	Horizontal channel	5.0	Soft gossan	<0.01[b]	Horizontal channel	5.0	Soft gossan	0.02
67-72 feet from shaft	540	Horizontal channel	5.0	Soft gossan	$\ll$0.01[b] [b]	Channel, right angles to shaft.	4.0	Soft gossan	2.15
West shaft, west side, 25-foot level.	543	Channel, right angles to shaft.	4.0	Soft gossan	>.1[b] 0.51	Channel, right angles to shaft.	----------	Soft gossan	2.85
West shaft, west side, 15-foot level.	544	Channel, right angles to shaft.	4.0	Soft gossan	$\gg$ .1[b] 2.00	----------	----------	----------	----------
West shaft									
East side from limestone upward.	LRP-36H-43	Channel at right angles to contact.	6.0	Soft gossan	0.12[a]	----------	----------	----------	----------
East side above LRP-36H-43.	LRP-35H-43	Channel at right angles to contact.	4.0	Soft gossan	1.65[a]	----------	----------	----------	----------

[a] Analyses by Smith-Emery Co., Los Angeles, California. Checked by chemical and spectrographic methods on composite samples.

[b] Spectrographic analyses by K. J. Murata, Geological Survey Chemistry Laboratory. Assays indicate only the order of magnitude of the amount of tin. Moderately strong lines of arsenic were noted in samples LRP-31H, 17H, 25H, and 27H-43.

[c] NOTE: These samples represent a total thickness of 4.5 feet at the base of the ore shoot. The average, weighted against length, of the samples is 0.63 percent.

[d] NOTE: Sample represents a thickness of about 4 feet at top of ore shoot.

spectrographic analysis. Two samples (LRP-4H and 5H-43, table 3) from pit 2, representing 4.5 feet on the footwall of the ore shoot, contained 0.35 and 1.03 percent of tin; weighted average 0.63 percent. Individual assays of cores and sludges from diamond-drill holes 7, 9, and 10 in this shoot showed 0.06 to 9.10 percent metallic tin (table 2). Weighted averages for short intervals might be on the order of 5 percent, but it is estimated that the entire ore shoot, as described above, averages between 1 and 2 percent tin. The Bureau of Mines estimates from diamond-drill-hole data that there is 1,440 tons of ore, containing 1.68 percent of metallic tin, in this ore shoot.

The remainder of the West gossan contains small scattered pods and streaks of high-grade tin ore which have been observed at intervals along the outcrop from pit 2 to pit 5; some ore was shipped from surface debris at pit 3. High-grade pods and streaks have been observed underground in the West shaft and at three places along the 23-foot-level drift (fig. 2). Such scattered pods cause the results of sampling to be very erratic and consequently accurate estimates of grade are impossible. Samples taken from the walls of the shaft by the Geological Survey and the Bureau of Mines ranged from 0.12 to 2.85 percent tin, and the operators obtained samples assaying as high as 19 percent.

Sufficient sampling has been done to show that the bulk of the gossan, exclusive of the streaks and pods of ore, carries little tin. Table 3, giving the results of sampling by both the Bureau of Mines and the Geological Survey shows that many of the samples contained less than 0.1 percent tin. This figure is exceeded only when high-grade pods are encountered. The small size and richness of these pods probably account for most of the apparent differences in sampling by different people. For example, the highest assay obtained by the Bureau of Mines in sampling pits 2, 3, 4, and 5 was 0.4 percent of tin. Yet a 2½-foot channel sample cut by Page in pit 2 contained 1.03 percent. Mallery's composite grab sample of the dumps of these pits contained 1.2 percent.

The Bureau of Mines sampled the west wall of the drift on the 23-foot level at 5-foot intervals. Fourteen of these samples contained less than 0.09 percent of tin; one contained 0.32 percent. Geological Survey spectrographic analyses of splits of these samples showed less than 0.04 percent of tin. The west fork of the drift was not sampled, but panning showed that the gossan contained only a trace of cassiterite. In limestone, near the face of the east drift, a streak of cassiterite with tourmaline and micaceous minerals, several feet long and one-eighth to 3 inches wide, assayed up to 50 percent of tin according to Mallery. Another veinlet of similar mineralogy is exposed in the back of the drift 45 feet from the shaft. A third veinlet rich in cassiterite was observed in limonite on the east wall of the drift. These veinlets were not included in the Bureau of Mines samples from the drift.

The East gossan is irregularly lenticular in shape and is connected with the gossan at the East shaft by a small body of magnetite. It is 100 feet long and as much as 30 feet wide. Like the West gossan it dips gently northward; shallow diamond-drill holes beneath the gossan penetrated only barren limestone indicating that it probably extends no more than 10 or 15 feet down the dip (pl. 6 and table 2).

High-grade ore was observed in both limestone and gossan in pit 8. One channel sample across limestone (table 3) assayed 2.43 percent tin

over a length of 3 feet. Below this limestone another sample in limestone, 1.7 feet long, was shown by the spectroscope to contain much more than 1 percent of tin. In the surface debris just south and west of this pit Mallery recovered most of the ore for his December 1944 shipment which assayed 48.90 percent tin. On the surface a band of cassiterite-rich gossan extends from pit 8 westward nearly to the collar of drill-hole 3. This exposure is 35 feet long and 10 feet wide. It is estimated that this cassiterite-rich gossan may contain 2 percent tin, but the rest of the gossan probably contains 0.1 percent or less of tin.

There are three areas from which placer tin might be obtained: (1) the soil between the Meeke pit, pit 3, and the arroyo, (2) the soil for 300 feet down the slope and southeast of the east gossan, and (3) the soil-covered flat approximately 500 feet southeast of the mine workings.

The Geological Survey sampled the soil in the area below pit 3 with 4 bore holes 6 inches in diameter put down to bedrock. Approximately 533 yards of dirt estimated to contain 15 pounds of tin per yard and 460 yards estimated to contain 3 to 15 pounds of tin, were indicated. Five similar samples of the soil southeast of the East gossan contained 28.8, 9.6, 4.5, 4.2 and 3.6 pounds of tin per yard. The first two samples (28.8 and 9.6 pounds) represent an area 50 by 50 feet at the south end of the East gossan. Many high-grade nodules have been picked from this dirt, but there remains some 270 yards estimated to contain about 21 pounds of tin per yard. The other 3 samples represent material ranging from 20 to 48 inches in depth over an area 250 feet long and 70 feet wide, amounting to 2,000 yards of clayey sand containing about 4.2 pounds of tin per yard.

The third possible area of placer ground, a flat area below the granite shown on plate 6, and above the brecciated dolomite ledges (pl. 5), received tin-bearing float from both the East and West gossan areas. The tin-bearing material extends over a triangular area of 90,000 square feet, and probably has an average depth of 3 feet. Panned samples were estimated to contain one to three pounds of tin per yard. This area is estimated to contain 10,000 yards of clayey soil that might assay 1.5 pounds of tin. No more than traces of tin have been found at any other area lower down on the slope below the Meeke deposit.

Reserves. The reserves of tin ore on the Meeke property are not large. In the West gossan the known ore shoot is estimated, on the basis of diamond drilling, to contain at least 1,440 tons of ore which will average 1.68 percent of tin. Geological considerations, plus assays, suggest that there are perhaps an additional 1,000 tons of gossan at the edges of the ore shoot that might contain on the order of 1.00 percent of tin. The main body of gossan exclusive of the ore shoot probably contains about 20,000 tons which would assay about 0.1 percent tin, but in which some small, higher-grade pods and lenses may be found.

The East gossan is estimated to contain 700 tons of iron oxides of which 300 tons are estimated to contain 2 percent of tin. The remainder of the body probably contains about 0.1 percent tin, though, as in the case of the West gossan, higher-grade pods may be found.

The placer reserves are estimated to be 800 yards containing 15 to 30 pounds, 2,460 yards containing 3 to 15 pounds, and 10,000 yards containing 1.5 pounds of tin per yard.

Table 4. Assay data, Upper Butler prospect

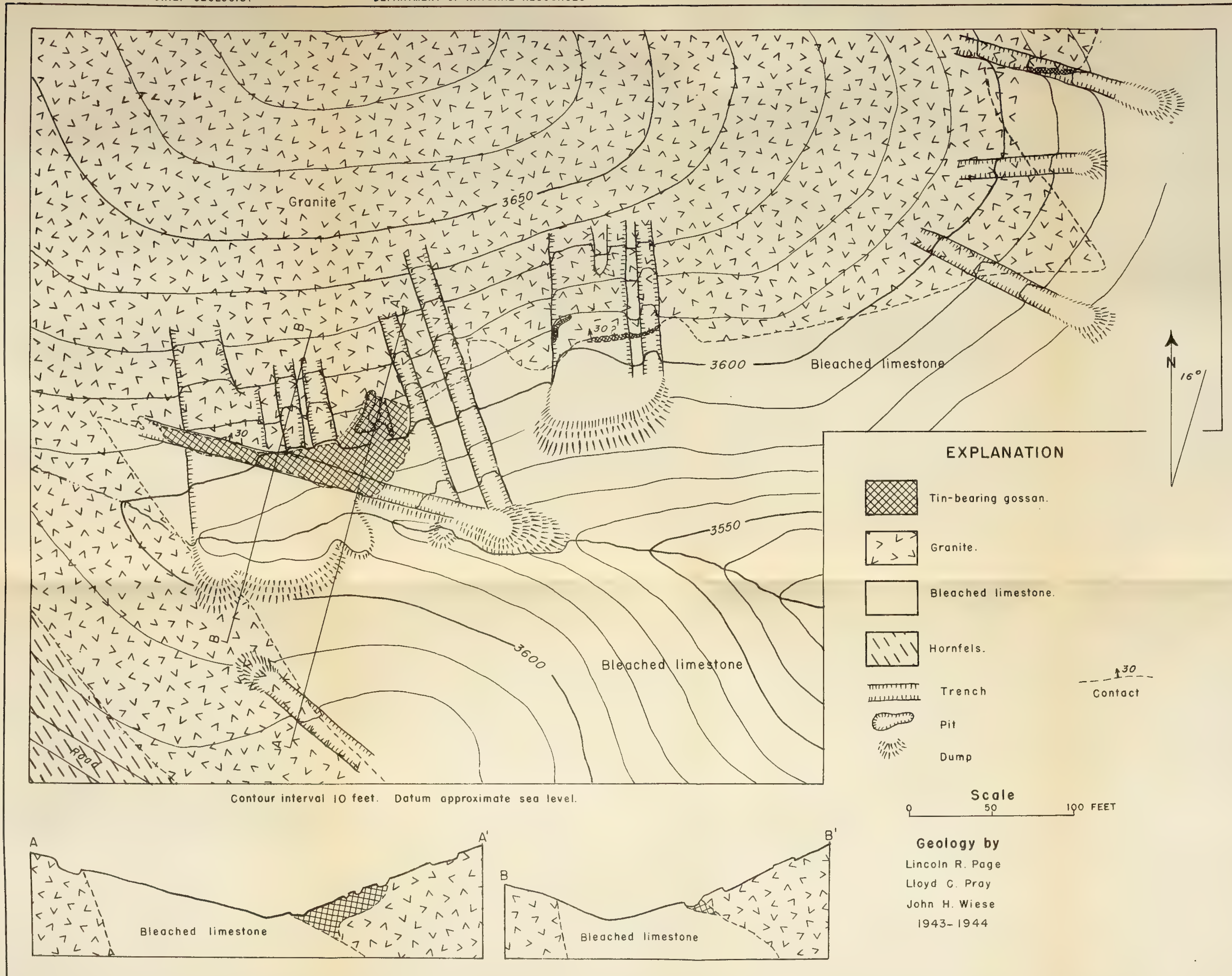
Geological Survey samples [a]

Location of samples	Sample number	Type of sample	Length of sample (feet)		Per-cent tin
Large tactite body. East-West bulldozer trench					
N. wall trench. 30 ft. from E. end of tactite	LRP-31H-43	Vertical channel	4	Rubbly gossan and magnetite	1.0
Across N. half of gossan, floor of trench at E. end	LRP-32H-43	Horizontal channel	5	Rubbly gossan and magnetite	1.0
S. half of gossan S. of LRP-32H-43	LRP-33H-43	Horizontal channel	3	Rubbly gossan and magnetite	0.5
30 feet E. of W. end. N. end of channel. 2 feet S. of contact	LRP-34H-43	Horizontal channel	7.5	Rubbly gossan and magnetite	0.5
Small tactite body at granite contact					
200 feet N.E. of LRP-32H-43	LRP-35H-43	Horizontal channel	2.5	Gossan	0.5

Bureau of Mines Samples

Location of samples	Sample number	Type of sample	Length of sample (feet)		Per-cent tin
Large tactite body. Samples along center of bulldozer trench					
25 to 50 feet from west contact	442	Horizontal channel	25	Gossan	0.36
50 to 75 feet from west contact	443	Horizontal channel	25	Gossan	0.64
75 to 100 feet from west contact	443	Horizontal channel	25	Gossan	0.89

[a] Spectrographic analyses by K. J. Murata, of the Geological Survey Chemical Laboratories. Assays indicate only the order of magnitude of the amount of tin. Moderately strong lines of arsenic were noted in samples LRP-33H-43.



ACCOMPANYING STATE MINERALOGIST'S REPORT XLII JANUARY 1946

GEOLOGIC MAP AND SECTIONS OF UPPER BUTLER TIN PROSPECT, KERN COUNTY, CALIFORNIA

Upper Butler Prospect

The Upper Butler tin prospect is in section 30, T. 9 N., R. 17 W., S. B., about 200 feet east of the road to the Kelso zinc mine (pl. 5). It is at an altitude of approximately 3,600 feet, on the north side of a small tributary gulch which opens southward into the valley near the mouth of Alamos Creek. Cassiterite was discovered at the Upper Butler property in 1942 by Willard Mallery, who traced tin-bearing float up the gulch from the valley. Prior to this time small prospect pits had been made on the property in search of iron ore.

Geology. The Upper Butler tin deposit consists of four bodies of tin-bearing iron oxide formed at the contact with granite by replacement of limestone and subsequent oxidation of the ore body (pl. 7). The granite is exposed on the slopes north and west of the deposits, partly surrounding a pointed salient of limestone. It is composed of equal parts of quartz and white feldspar intergrown in a semi-graphic texture. The individual grains average one-eighth inch in size, but at the contact they are smaller. Occasional specks of greenish hornblende or biotite, partly altered to chlorite, are scattered through the rock.

White, massive, fine-grained, recrystallized limestone crops out prominently on the steep slopes south and east of the tin deposits. Bedding in the limestone is very indistinct, but appears to dip northeast 35° to 40°. The northern boundary of the limestone is probably a north-dipping intrusive contact whose position is controlled in part by the bedding. On the west, the limestone lies against granite which was apparently intruded along a fault between the limestone and hornfels.

Epidote-garnet hornfels is poorly exposed in the gulch east of the ore bodies and on the slope southwest of the granite. In contrast with the massive limestone, it is thinly bedded and includes thin layers of coarse-grained marble. The attitude of the beds in the hornfels varies considerably, probably as the result of minor folding and faulting, but in general the dips are steeply to the north.

Structure. The boundary of the limestone and granite in the southwestern part of the mapped area (pl. 7) is probably a fault striking about N. 50° W. and dipping steeply. It may be of post-granite age, but probably was an earlier fault along which the granite was emplaced. A similar pre-granite fault probably caused the apparent offset of the granite contact near the northeast corner of the mapped area. Between these two faults, the intrusive contact along which the tactite bodies were formed appears to dip 30° to 35° N.

Size and Grade of the Tin Deposit. One large and three small bodies of gossan have been formed by the weathering of iron-rich deposits at the contact of granite and limestone. The large body is about 150 feet long, 15 to 60 feet wide, and has a maximum vertical exposure of 29 feet. The footwall and west end of the deposit are not exposed, but the hanging-wall appears to dip 30° to 35° N. The tin-bearing rock exposed in bulldozer trenches consists mainly of red and brown iron oxides which grade, near the hanging-wall, into green, yellowish, and red clayey material. The red clayey material contains scattered fine-grained colorless tourmaline and micaceous minerals similar to the vermiculite at the Meeke deposit. Some of the clay may have been derived from tactite containing amphibole and ludwigite similar to that at Crow-

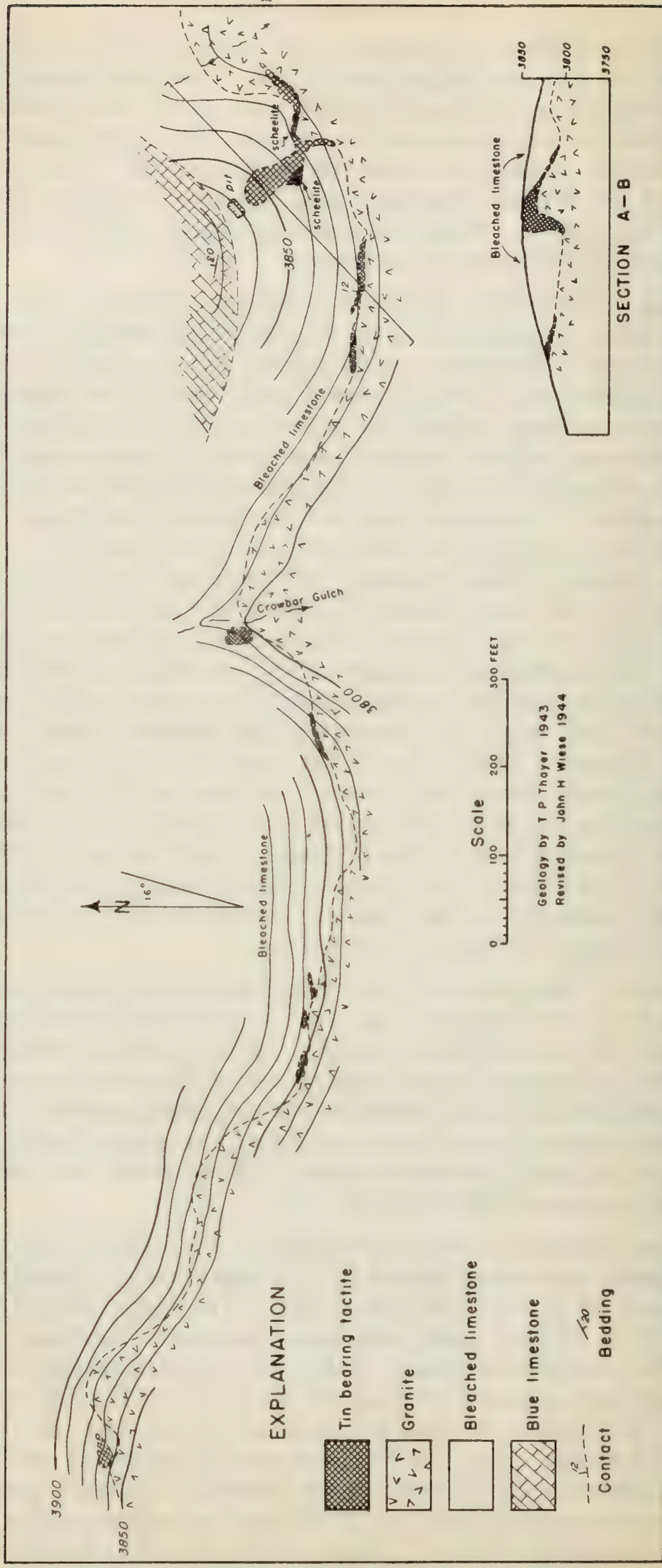


FIG. 3. Geologic map of Crowbar Gulch tin prospect.

bar Gulch and the Gray Eagle claim. Near the southeast corner of the gossan, the ore consists predominantly of magnetite and red clayey iron oxide. At the northeast corner, in the vicinity of the old pits, the gossan is mainly jaspery limonite. Two small inclusions of limestone, one of which is shown on the map, were found in the gossan.

Assays of samples taken by the Bureau of Mines and by the Geological Survey (table 4) from the bulldozer trench parallel to the footwall of the ore body, suggest that the ore averages about 0.5 percent of tin. Four channel samples taken by the Survey across the gossan body exposed in this trench contained 0.5 to 1.0 percent of tin and samples taken by the Bureau of Mines along the gossan body in the same trench contained 0.36 to 0.89 percent of tin. Visible cassiterite is very scarce, probably because it is masked by iron oxides. However, it is possible that some of the tin may be in other minerals, such as the ludwigite.

The main Upper Butler gossan body is irregular in shape and, as mapped, it covers an area of approximately 3,500 square feet. If its shape is that shown on the sections (pl. 7), the inferred reserves are about 2,300 tons of ore containing between 0.5 and 1.0 percent of tin.

The second largest body of gossan is 100 feet east of the main deposit. It is 50 feet long and 2.5 feet thick. It strikes N. 75° E. and dips 30° NW. One sample cut across the body assayed 0.5 percent of tin. There are two other small gossan bodies. One is along the contact near the northeast corner of the area, and the other is a small inclusion of replaced limestone in the granite. These three bodies together may contain about 150 tons of indicated ore averaging 0.5 percent of tin.

Crowbar Gulch Prospect

The Crowbar Gulch prospect includes a number of small tin-bearing tactite bodies along the contact between limestone and granite about 1½ miles southeast of the Meeke deposit. It may be reached by a branch of the dirt road from Alamos Creek to Black Canyon which leads to within 500 feet of the spring at the granite contact in Crowbar Gulch. The prospect is included in the Dunton prospecting permit held by Willard Mallery and Dana Hogan. Exploratory work, done in 1943, consists of four shallow trenches and a 15-foot pit at the eastern end of the deposit.

The following description is based in part on a report by T. P. Thayer, who mapped the deposit in September 1943, and in part on work by Wiese in 1945.

Geology. All of the tin deposits are in limestone along the intrusive contact of granite and dip 10° to 30° N. The bleached limestone along the contact is similar to that of the other tin deposits of the district, and probably extends 100 to 140 feet outward from the granite although fingers of bleached limestone penetrate some distance farther into the overlying blue limestone. There is a well-marked boundary between the bleached and the blue, medium-grained limestone. The granite is a medium-grained gray rock made up almost wholly of quartz and feldspar. Near the contact it is finer grained, approaching aplite in texture.

Mineralogy. The tin-bearing tactite bodies contain amphibole, garnet, ludwigite, quartz, cassiterite, magnetite, scheelite, maghemite,[4] chlo-

[4] Maghemite, allied to the spinel group, is an isometric magnetic mineral composed of ferric oxide (Fe_2O_3).

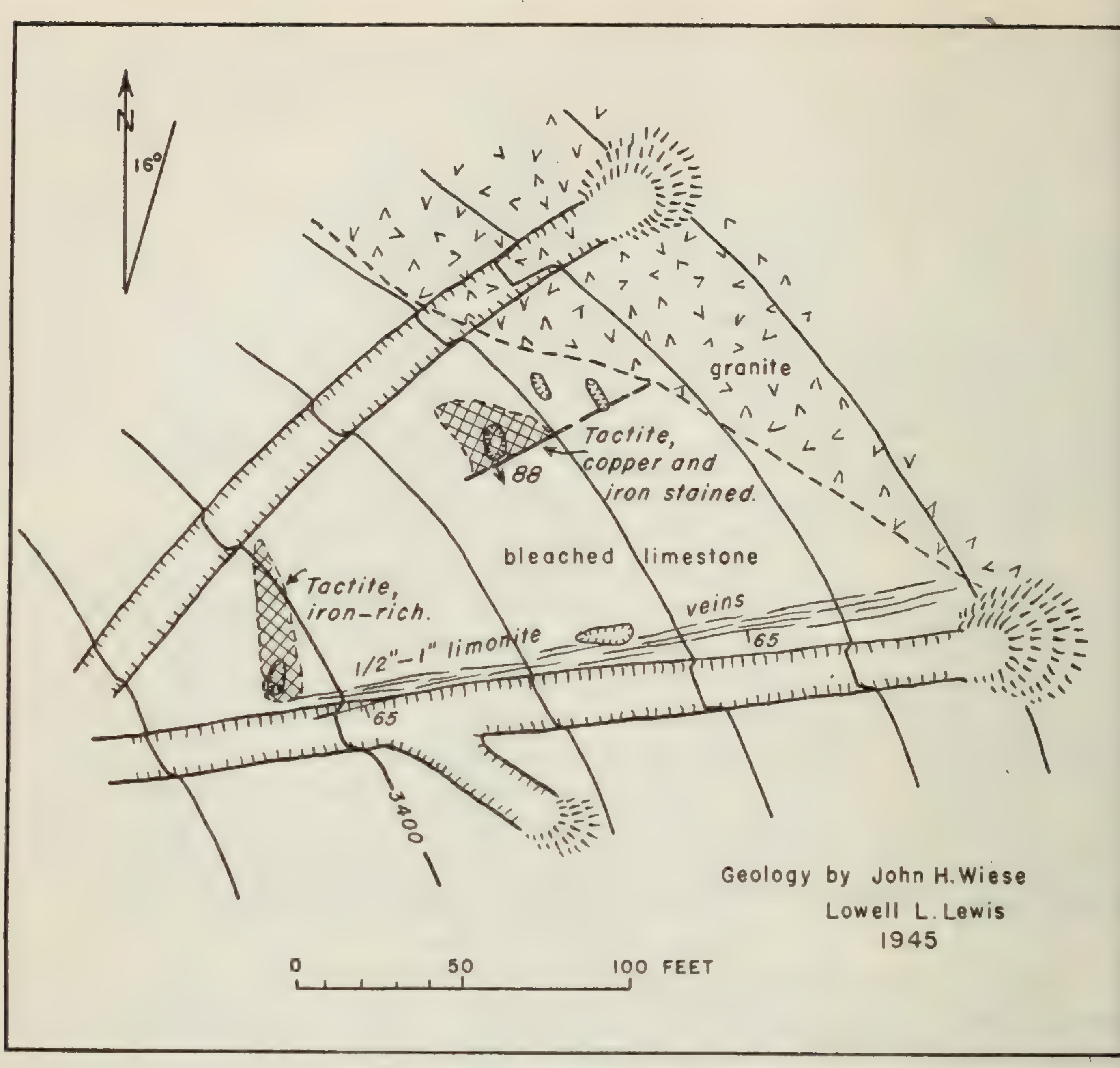


FIG. 4. Lower Butler tin prospect.

rite, and calcite formed by the replacement of limestone. However, not all these minerals occur in the same body. The only traces of cassiterite were found in concentrates from the panning of large samples. Ludwigite, an iron-magnesium (manganese) borate, was identified by Miss Glass as a common mineral in the two largest tactite bodies, where it is associated with a radial fibrous amphibole, probably pargasite, and magnetite. Miss Glass' work suggests that the ludwigite may contain some of the tin reported in assays of these tactite bodies. Colorless scheelite forms a fine-grained matrix surrounding some of the amphibole and iron oxides in the easternmost tactite body. Garnet and epidote are more common in the tactite at the western end of the deposit. Magnetite in varying amounts is present in all the tactite, in places forming as much as 40 percent of the rock.

Size and Grade of the Tin Deposits. Two large and eleven smaller tin-bearing tactite bodies have been mapped along the granite contact. The largest, exposed over an area of about 300 square feet, near the east end of the map area, has been explored by three trenches and a pit 15 feet deep. According to chip samples taken by Mallery and others, the tactite contains from 0.15 to 0.90 percent of tin and appears to average about 0.3 percent. The inferred shape of this body at depth is shown in figure 3.

The tin-bearing tactite body in Crowbar Gulch is exposed over an area of about 500 square feet and is reported by Mallery to contain about 0.8 percent of tin. The eleven smaller tactite deposits average about 0.3 percent of tin, according to Mallery.

These tactite bodies would contain a combined total of about 500 tons of rock per foot of depth, if grouped together, and provided they did not change in shape downward. It appears likely, however, that they pinch out within 15 feet of the surface, or about 35 feet down the dip. The quantity of recoverable tin is unknown for part of that shown in assays may be contained in the mineral ludwigite rather than in cassiterite.

The eastern tactite body probably contains 4,000 tons with 0.3 percent of tin; the tactite at Crowbar Gulch may contain 1,000 tons with 0.8 percent of tin; and the other tactite bodies probably total 1,200 tons containing an average of 0.3 percent of tin.

Lower Butler Prospect

The Lower Butler prospect is about 2,000 feet east of the Upper Butler and within a few hundred feet of the edge of the valley alluvium (pl. 5). The deposit consists of two small iron-rich tactite bodies in bleached recrystallized limestone adjacent to granite. It was prospected by means of two shallow bulldozer cuts and five small pits (fig. 4).

The bleached limestone, a massive homogeneous fine-grained rock with no apparent bedding is similar to that at the Meeke, Upper Butler, and Crowbar Gulch deposits. A strong set of joints strike east and dip steeply south. The granite does not crop out, but small fragments of float are numerous in the area mapped as granite.

The tactite is deeply weathered, and consists predominantly of massive brown garnet with variable quantities of fine-grained magnetite, hematite, and limonite. Thin films of malachite and chrysocolla coat fractures in the north tactite body, but no sulfides were seen. No cassiterite was observed in hand specimens and only rarely can it be recovered by panning. Willard Mallery, the discoverer of the prospect, collected one grab sample assaying 1.9 percent tin from the surface, but his subsequent assays of other similar samples revealed only traces of tin.

At the south edge of the deposit, barren limonite veins one-half to 1 inch wide fill a series of fractures striking N. 85° E. and dipping 65° SE.

Gray Eagle Prospect

The Gray Eagle prospect (or Discovery prospect of plate 5), about 300 yards west of the large spring at the head of Alamos Creek, was the first place in the district where tin was found. This property is on public land, on a mineral claim held by Willard Mallery and Dana Hogan.

A small body of tin-bearing, iron-rich tactite about 6 feet long and 18 inches wide is exposed in a shallow pit at the contact between limestone and granite. Exposures in the vicinity of the deposit are poor, but magnetite float in the gulch above the pit suggests the existence of other similar tactite bodies.

Miss Glass identified the tactite minerals as maghemite (the magnetic form of ferric oxide), magnetite, ludwigite, and an altered amphibole, probably anthophyllite. These minerals, coated by man-

ganese oxide, all have pronounced fibrous structure and are associated with magnetite and small amounts of arsenopyrite and molybdenite. Cassiterite occurs as finely disseminated grains practically invisible in hand specimens but may be recovered by panning. Mallery collected some specimens of this rock which assayed as much as 3 percent of tin; other samples contained less. Some of the tin may be contained in ludwigite and other minerals.

Dunton Prospect

The Dunton Prospect (pl. 5) is about three-fourths of a mile southwest of the Crowbar Gulch deposit. It is on the north edge of a limestone salient that caps the second ridge south of Black Canyon. The deposit, prospected for iron by two bulldozer trenches, is primarily magnetite tactite. Two grab samples taken by Mallery assayed 1.42 and 3.15 percent of tin, but five samples taken subsequently by private engineers contained no tin. Page obtained only traces of cassiterite on panning two grab samples of the magnetite ore exposed in the bulldozer trenches. No cassiterite was observed in place.

SPECIAL ARTICLES

CALIFORNIA'S MINERALS FOR TOMORROW *

By Walter W. Bradley, State Mineralogist

Friends of the Radio audience:

Most people think of California's mines and minerals in terms of gold mining; but gold today is only one of this State's sixty different mineral substances produced annually on a commercial basis. As everyone knows, the West's gold mines took an unwarranted beating during the war period through being closed down by government fiat as being ''non-essential.'' We look for gold mining in California to stage a come-back. Present indications point to that; but they also indicate that it will be a gradual process, owing to shortage and higher cost of labor and lack of immediate supplies of machinery, parts and other necessary items.

California has a variety of metals other than gold. Among these should be mentioned, particularly, quicksilver, iron, chromium, manganese, tungsten, molybdenum, copper, lead, zinc, silver, platinum. Of those of strategic importance during the war, the immediate future for chromium, manganese, tungsten, and quicksilver is somewhat uncertain. Research work being done by the United States Bureau of Mines through a pilot-plant electric furnace at Shasta Dam gives promise of showing an avenue for the utilization of our chrome, manganese, tungsten, and molybdenum, in the preparation of their several ferro-alloys in the electric furnace with local iron ores. They will also have a definite value in the continuance and further development of the steel industry already begun under the stimulation of war-time demand with the Kaiser plant at Fontana. There is a sizeable market on the West Coast for the products of the blast-furnace and rolling mills, and California has the iron ores to supply the necessary raw materials. Magnesium is another metal whose future appears promising here.

Quicksilver is one of California's specialties, yielding normally more than 60 percent of the domestic output. It is important, alike in war and peace, in the manufacture of drugs, detonators (for mining and quarrying as well as in ammunition), various industrial and scientific applications in addition to the new dry-cell electric battery. The immediate future of our quicksilver mines is just now darkened by large importations in recent weeks of Spanish metal.

California's mineral resource of greatest annual productive value is, of course, petroleum. Most of us think of this liquid out of the ground, (''black-gold'' sometimes called), only as a fuel and as a source of lubricants. It is also already an outstanding raw material source for a growing line of chemical industries: of derivatives used as bases for the manufacture of synthetic rubber to mention only one of a large number. Natural gas, in part accompanying crude oil, but obtained

* A radio address broadcast over KFRC October 7, 1945, on the program of the State Chamber of Commerce, *California Cavalcade.* Manuscript submitted for publication January 4, 1946.

in important quantities in several fields as "dry" gas without oil, is a fuel particularly useful in domestic service as well as industrial and preferable in some of the latter to other forms of fuel.

Great as has been California's yield of gold, quicksilver, tungsten, and other metals in years past, her mineral industries have shown greater progress during the past 20 years in development and utilization of the nonmetallics—those substances mined and quarried, not for the reduction of a specific metal, but for their part in various chemical, industrial, and construction processes. Of these California has a long list. Their slow recognition and development has been due to higher costs and to smaller population than in the highly industrialized East. The West is growing. The gradual growth of the past 20 years has received an added impetus during the war years. Many plants and industries established and the accrued population are going to remain. California has the varieties of raw materials needed and many of them in ample reserves upon which to continue and expand those industries already established. Also to build others.

The chemical industries in particular, depend upon minerals for a substantial part of their essential raw materials, and chemical processes form the backbone of industrialism.

The outstanding feature of California's mineral resources is their remarkable diversity and number. Three mineral substances stand out above all the rest in number and variety of uses in the chemical and industrial field: sulphur, salt, and limestone. All three are employed in enormous quantities either as active reagents or as components of finished products. Sulphur, both elemental and in the form of iron sulphide, the mineral pyrite, is the source for manufacture of sulphuric acid, indispensable in industry. In fact, sulphuric acid has been designated "the old warhorse" of chemical manufacture. It is used primarily as a reagent in the fertilizer, petroleum-refining, and a host of other chemical and processing industries. The principal world source, today, of sulphur is Texas. In California, while we have some deposits of sulphur, they are not as important as pyrite in our commercial supply. Between 1934 and 1943, California's production of pyrite ranged between 64,000 and 117,000 net tons per year.

In the United States, salt consumption between 1918 and 1940 ranged from 6,000,000 to 9,000,000 tons, annually, following which, due to the growing demands for many chemical products to supply war needs, it went up to a record of over 15,000,000 tons in 1943. A chart recently published nationally by one of the large salt producers lists some 1400 different uses for our household friend, "common salt." As a chemical raw material it is utilized particularly in the manufacture of such alkalies as soda ash, bicarbonate of soda, and caustic soda; though in California those products are obtained largely from processing the natural-occurring mineral forms. In California, salt production reached a high just under 700,000 tons and $2,000,000 in value in 1942. As to reserves, this State's output of sodium chloride is limited only by the capacity of plants that may be built to crystallize it from sea water and from the desert dry lakes.

Lime has been called "the king of the bases", and is, as we have already noted, one of the top trinity of important chemical and industrial materials. It is used in both the raw limestone form and calcined to

lime, the oxide. Included among the more important products requiring this base are: alkalies, asphalts, bleaching compounds, explosives, glass, insecticides, leather tanning, rubber, soap, steel fluxing, sugar, textiles. The early output of calcined lime in California was used entirely for structural purposes; but today other purposes take practically all of it. The largest tonnage of limestone goes into the manufacture of portland cement for structural uses of all types; but "industrial" limestone has recently been shipped from 19 properties in 11 counties totaling approximately a half-million tons worth $1\frac{1}{2}$ million dollars.

I will speak briefly of other important nonmetallics in California, including building stone, magnesite, crushed rock-sand-gravel, barite, clays, diatomite, dolomite, feldspar, gypsum, mineral water, pumice, silica, andalusite, soapstone and talc, also the saline group which includes borax, magnesium salts, potash, sodium salts.

Of building stones, California has many fine and serviceable kinds of granite, sandstone, marble, and slate, but these have in considerable part been replaced by re-inforced concrete structures and by ceramic products such as architectural terra cotta and decorative tile. Our clays are widely and increasingly being used for ceramic purposes. More than a half-million tons of the raw clays worth over a million dollars annually are turned out for the market in finished products valued at from 12 to 15 million dollars. Besides architectural terra cotta and decorative tile just mentioned, we may note the following: drain tile, roofing tile, sewer pipe, red earthenware, stoneware and chemical stoneware, chinaware and semi-vitreous tableware, high-temperature cements, art pottery, sanitary ware, plumbing fixtures, electrical porcelains, dolls, glazed flower pots, and many other items. It is likely that some day our clays may be the source for an aluminum industry, but thus far the processes being tried have not attained a commercial basis. Andalusite, an aluminum silicate, the so-called "spark-plug ore" has had a romantic history which cannot be related here for lack of time. Suffice it to say that from the status of a museum specimen mineral, the finding of commercial quantities in the White Mountains, Mono County, California at 10,000 feet above sea-level, put that part of the State on the industrial map. It is used in high-tension electrical porcelains.

Magnesite has been used in part for the production of the metal, magnesium, but mostly for structural purposes and for refractory brick to line metallurgical furnaces. As a companion to portland cement, crushed rock, sand and gravel are the necessary components for concrete aggregate in a wide variety of structures: dams, buildings, residences, highway pavements. To list the kinds and varieties of rock utilized commercially under this heading would be to run almost the entire gamut of the classification scale. Much depends on the kind available in a given district. Those which give the most satisfactory service are the basalts and other hard, dense, igneous rocks which break with sharp, clean edges. In many localities, river-wash boulders form an important source of such material.

Barite has a variety of uses, depending upon its chemical and physical properties. Its barium content makes it useful in the barium chemical and glass industries, a good white color is an asset in its employment in the paint, lithopone, and paper industries, and its high specific gravity gives it value as an oil-well drilling mud.

Some 85 to 90 percent of our domestic output of diatomaceous earth (diatomite) comes from three counties in California—Santa Barbara, Los Angeles, and Monterey—principally the first named. It is employed mainly in filtration of liquids (as in sugar refining) and in insulation. Dolomite, a double carbonate of lime and magnesia has been used in the past largely as a source of carbon-dioxide gas and as a refractory liner in open-hearth steel furnaces. More recently its magnesium content is being extracted in a process involving both sea-water and the calcined dolomite. California has adequate reserves of both. Feldspar is an important raw material in pottery manufacture, as well as in glass and enamelware, soaps, and abrasives.

Gypsum is the base for hard-wall plasters, and fire-resistant gypsum board. It is also used as a soil-corrector in agriculture, and as a retarder to premature setting in portland cement. Mineral springs are many and varied in California, and have valuable therapeutic properties. Many millions of gallons are bottled for distribution and sale each year averaging around a million dollars worth. A considerable number of the springs have accommodations for guests and patients. Pumice has been used in light-weight concrete aggregate and acoustical plaster, also in abrasives.

Silica both in the form of quartz and sand has a variety of uses, such as for glass manufacture, refractories, ceramic mixtures, and as an abrasive. Talc, with soapstone (an impure, massive talc) is a particularly useful and important mineral. Besides for "milady's" face powder, it has applications in paint, paper, and rubber manufacture, also in ceramics. In certain types of modern tableware developed in California, as much as 85 percent talc is used in the basic mix, giving the fired ware a remarkable toughness and resistance to shock. The soapstone grades are used mainly for roofing granules and as a filler in roofing paper.

The salines constitute a particularly important group in the chemical industries. Common salt, in this group, has already been discussed. Except for the nitrates, California seems well supplied with reserves of all of the most needed and useful. This State is the principal world source today, of borax. It is both mined in solid, crystalline form in Kern County, and processed from the brine of Searles Lake in San Bernardino County. It plays an especial role in many industrial processes and products. Its development in California has had a most interesting history. Magnesium salts are obtained as by-products from the salt-works bitterns, and include the basic carbonate, hydroxide, chloride, and sulphate. Potash salts stand high on the value list of chemicals. In California, they are separated by crystallization from the brine of Searles Lake, along with borax and several of the sodium salts, such as soda ash, trona, and salt cake. Besides their role in the chemical trade, potash salts are leaders in the agricultural fertilizer field. Some minor saline products on California's list are bromine, calcium chloride and iodine.

In the short time available tonight we have been able merely to touch upon the high-lights of California's mineral resources. We hope we have given you at least some appreciation of their diversity and their value to our State's economy.

RELOCATION OF CLAIM BY ORIGINAL LOCATOR
STATE OF CALIFORNIA DISTRICT COURT OF APPEAL

[Civ. No. 3298. Fourth Dist. Nov. 8, 1945.]

PAUL JUDSON, Respondent, v. E. H. HERRINGTON, Appellant.

[1] **Appeal—Law of Case—Discretion.**—The application of the rule of the law of the case rests in the discretion of the reviewing court.

[2] **Mines—Estate and Rights of Locator—Title.**—The title of the grantee of a mining claim is not affected by a prior location notice filed by his predecessor in interest and involving other land.

[3] **Id.—Locating of Claims—Relocation.**—Location of mining claims on the public domain of the United States are not void under Civ. Code, § 1426s; Pub. Res. Code, § 2321, which disqualify a locator failing to do required development work from again locating on the same ground or any part thereof within three years, in view of the federal law permitting location in the same manner as though no prior location had been made. (See 9 U. S. Stats. at L. 452.)

[4] **Id.—Estate and Rights of Locator—Title.**—An attempted location of a mining claim creates no valid right against another where he and his predecessor in interest, the original locator, have had possession of the property and worked the claim for more than five years. (30 U. S. C. A. § 38; U. S. Rev. Stats. § 2332.)

APPEAL from a judgment of the Superior Court of San Bernardino County. Benjamin F. Warmer, Judge. Affirmed.

Action to quiet title to mining claims. Judgment for plaintiff affirmed.

Willedd Andrews for Appellant.

Vincent & Eaton and Eldred L. Eaton for Respondent.

MARKS, J.—This is an appeal from a judgment which quieted plaintiff's title to two mining claims, Brandywine No. 1, and Brandywine No. 2, in San Bernardino County.

The case has been here before (*Judson* v. *Herrington,* 55 Cal. App. 2d 476 [130 P. 2d 803]). There is no serious difference in the material evidence introduced at the two trials and the issues argued now were covered in the earlier opinion where there is a detailed statement of facts which need not be repeated here.

Defendant claims there is a material difference in the evidence introduced in the second trial from that before the court in the first. He stresses the testimony of W. L. Page, the original locator of the two claims, to the effect that prior locations had been made by him in 1928. An examination of the record discloses that the date "1928" occurred only in the questions propounded to Mr. Page by counsel for defendant which were answered in such a manner as to indicate that he had located the property covered by the Brandywine claims in 1928, two years prior to the locations of the claims on January 4, 1930, under which plaintiff claims. Later in the cross-examination Mr. Page realized that he had been led into testifying concerning these locations as though they had been made in 1928. He then corrected his testimony and said that he first located the claims under other names in 1927, did no assessment work on them and again located them on January 4, 1930. No location notices filed in 1928 were introduced but the location notices of 1927 were pro-

duced and we are satisfied that Mr. Page did not locate these claims in 1928, nor at any other times other than 1927 and in 1930. It is also clear that he did no assessment work on the property following the 1927 locations but built the necessary monuments, posted and recorded the location notices and otherwise conformed to the federal laws in locating the properties in 1930 as placer claims containing bentonite.

[1] The questions presented by defendant were decided on the former appeal upon practically the same evidence which we now have before us. As the application of the rule of the law of the case seems now to be somewhat a matter of discretion vested in the courts (*England* v. *Hospital of the Good Samaritan,* 14 Cal. 2d 791 [97 P. 2d 813]) we will consider the questions presented and briefly outline the evidence necessary to understand them.

On March 17, 1933, Page and his wife conveyed the two claims to E. T. Webb, and on August 8, 1933, Webb conveyed them to Paul Judson, plaintiff in this action.

Early in 1930, Page leased the property to Lewis Thompson who went into possession, had the property surveyed, erected posts at the sites of the monuments and commenced mining operations, shipping and selling four carloads of bentonite. His workings ran into sandstone and he abandoned the property in the fall of 1930. Page then leased the claims to Martinez and Becker who went into possession in 1931, and conducted active mining operations for several years. It seems clear that mining operations were carried on for a number of years by the respective owners or their lessees from early in 1930 to 1938 or 1939 and that bentonite was mined, shipped and sold from the claims during that period. Further, the owners took advantage of the various moratorium statutes although mining operations were continued so that the annual assessment work was done. (See, *Judson* v. *Herrington, supra.*)

On July 1, 1935, H. E. Herrington and his associates posted and recorded location notices on property which included the two claims in question here. Later Herrington acquired whatever interest his associates had in the property. On July 27, 1939, Judson started this action to quiet his title to the two Brandywine claims. At the first trial in February, 1941, judgment was rendered in favor of the defendant Herrington which was reversed on appeal. At the second trial in April, 1944, plaintiff had judgment quieting his title to the two bentonite claims.

[2] Defendant introduced in evidence a location notice signed by Page, dated May 7, 1929, recorded May 11, 1929, and argues that this is fatal to the claim of plaintiff under the 1930 locations. There is nothing in the 1929 location notice indicating that it was upon the property covered by either of the Brandywine locations. Page testified, ". . . but it didn't cover this ground where the Brandywine was at all. . . . It was different ground." We fail to see how the 1929 location can have any bearing on this case.

[3] Defendant's brief is largely devoted to arguments based on purported 1928 locations, which were not made, and on the 1929 location which was on property not involved here. He concludes his argument by reference to section 1426*s* of the Civil Code, now section 2321 of the Public Resources Code, which provides in effect that if a locator fails to do the required development work on his claim he shall be dis-

qualified from relocating the same ground or any part thereof for three years and that any attempted location thereof by him within such time shall be void. As the 1927 locations were made within three years prior to January 4, 1930, and as we assume that the location covered all or a part of the same property we should consider that question.

It is the contention of defendant that the locations of the two claims by Page in January were void under the California law because Page had located the same claims within the prior three years and had failed to do any assessment work under the earlier locations.

Section 4620, U. S. Comp. Stats. 1918, section 2324, U. S. Revised Stats., section 28, ch. 2, title 30, U. S. C. A. provide in effect that where the required assessment work is not done the claim shall be open to location in the same manner as though no prior location had been made. (*Kramer* v. *Gladding, McBean & Co.,* 30 Cal. App. 2d 98 [85 P. 2d 552].) Defendant admits this general rule but urges that the provisions of the California statute prohibits the original locator from again locating the claims within three years but that under the federal rule any other person may locate the property within that time.

The right of an original locator who had done no assessment work to again locate the claim, was before the court in *Rohn* v. *Iron Chief Mining Co.,* 186 Cal. 703 [200 P. 644], and was disposed of as follows: "We are of the opinion that the language of section 2324 does not have the effect contended for by the learned author above mentioned. It expressly declares that if the work required is not done within the year specified, the claim or mine 'shall be open to relocation as if no location of the same had ever been made.' In other words, it is then to be considered as vacant public land of the United States, subject to entry by any qualified person, as provided in section 2319 [6 Fed. Stats. Ann., p. 509; U. S. Comp. Stats., sec. 4614]. If the original locator is a qualified person, he is as eligible to make a relocation under this language as a stranger would be."

The effect of the California Code provisions now before us were not considered in the Rohn case. It is well settled that a law passed by one of the States of the Union cannot limit or abridge a constitutional federal enactment; that the federal law must control where the two come into conflict. (*Belk* v. *Meagher,* 104 U. S. 279 [26 L. Ed. 735]; *Florida* v. *Mellon,* 273 U. S. 12 [47 S. Ct. 265, 71 L. Ed. 511]; *City of San Diego* v. *Van Winkle,* 69 Cal. App. 2d ___ [158 P. 2d 774].)

Section three of the act of Congress of September 9, 1850, (9 U. S. Stats. at Large, 452) admitting California into the Union contained the following: "That the said State of California is admitted into the Union upon the express condition that the people of said State, through their legislature or otherwise, shall never interfere with the primary disposal of the public lands within its limits, and shall pass no law and do no act whereby the title of the United States to, and right to dispose of, the same shall be impaired or questioned; . . ." (See, *Donnelly* v. *United States,* 228 U. S. 243, 33 Sup. Ct. 449 [57 L. Ed. 820].)

It seems clear that an attempt by the California Legislature to limit the right of a citizen, given by federal law, to locate mineral claims on property which is part of the public domain of the United States cannot be upheld. This was expressly held in *Dalton* v. *Clark,* 129 Cal. App. 136 [18 P. 2d 752].

[4] Another reason for upholding the judgment in favor of plaintiff is found in section 38, chapter 2, title 30, U. S. C. A. (U. S. Rev. Stats., § 2332) which provides in effect that when a person or an association and their grantors have held and worked their claims for the period of the state statute of limitations (in California five years), evidence of such possession and working the claims shall establish the right to a patent. This section has been frequently construed by the courts of this state which have consistently held that proof of possession and working claims for five years obviates the necessity of proof of valid location notices and is equivalent to proof of valid locations. (See, *Altoona etc. Co.* v. *Integral etc. Co.,* 114 Cal. 100 [45 P. 1047]; *Dalton* v. *Clark, supra; McLean* v. *Ladewig,* 2 Cal. App. 2d 21 [37 P. 2d 502]; *Lind* v. *Baker,* 31 Cal. App. 631 [88 P. 2d 777]; *Judson* v. *Herrington, supra.*)

Here, Page and his successors in interest had possession of the property and mined, shipped and sold bentonite from it for more than five years after January 4, 1930. Proof of these facts is sufficient to establish the right to a patent without proof of the valid locations by Page. Defendant and his associates did not attempt to locate the claim until July 1, 1935, after the expiration of the five year period. At that time the claims were lawfully in the possession of plaintiff and were not open to location. The attempted locations of the claims by defendant and his associates could create no valid rights in them. (*Belk* v. *Meagher, supra; Ring* v. *United States Gypsum Co.,* 62 Cal. App. 87 [216 P. 409]; *Lind* v. *Baker, supra; Judson* v. *Herrington, supra.*)

The judgment is affirmed.

Barnard, P. J., and Griffin, J., concurred.

MINERAL EXHIBIT AND STATISTICS

ACCESSIONS TO THE EXHIBIT

By Henry H. Symons *

The Museum of the State Division of Mines possesses an exceptionally fine collection of rocks and minerals of both economic and academic value. It ranks among the first five of such collections in North America and contains not only specimens of most of the known minerals found in California, but much valuable and interesting material from other states and foreign countries as well.

The exhibit is daily visited by engineers, students, business men, and prospectors as well as tourists and sightseers. Besides its practical use in the economic development of California's mineral resources, the collection is a most valuable educational asset to the State and to San Francisco.

Mineral specimens suitable for exhibit purposes are solicited, and their donation will be appreciated by the State Division of Mines as well as by those who utilize the facilities of the collection.

Among the specimens received recently and catalogued for the Museum are the following:

21211 PREHNITE ($H_2Ca_2Al_2(SiO_4)_3$). From Vandermade quarry at Prospect Park, N. J. Donor: T. Orchard Lisle. November 1945. In case 132.

21212 Native GOLD, octahdrons from Alaska. Donor: Victor C. Heikes. November 1945. In safe 2.

21213 Native GOLD in shape of grasshopper from California. Donor: Victor C. Heikes. November 1945. In safe 2.

21214 TOPAZ ($Al(F,OH)_2SiO_2$) Massive. From Chesterfield County, South Carolina. Donor: John R. Callaham. November 1945. In case 137.

21215 STANNITE (sulphide of tin) with marmotite and pyrite, from Selkirks Range, Albert Canyon, British Columbia, 7½ miles from Silver Creek siding. Donor: Lt. Col. A. S. MacCulloch and R. A. Brooke. November 1945. In case 108.

21216 URANINITE—pitchblende (isometric). Uranate of uranyl lead, thorium, etc. Locality: Wood mine, Gilpin County, Colorado. 1889. Donor: Victor C. Heikes. December 1945. In case 150.

21217 CARNOTITE ORE. Locality: 13 miles south and east of Green River, Utah. Donor: Victor C. Heikes. December 1945. In case 145.
"Carnotite is found in this country in flat-lying soft sandstone beds as a deposit formed by the replacement of wood or other vegetable remains now fossilized." Frank Hess, Mineral Resources of the United States, 1918, Pt. I, p. 815.

21218 HEWETTITE (calcium vanadate). Locality: 13 miles south and east of Green River, Utah. Donor: Victor C. Heikes. December 1945. In case 145.

21219 CARNOTITE. Locality: Temple Mountain, Utah, near the Colorado state line. Donor: Victor C. Heikes. December 1945. In case 145.

21220 HACKMANITE—a variety of sodalite. Pungannon Township, Ontario, Canada. Donor: Hugh S. Spence. December 1945. Note: This mineral fluoresces pink and when exposed to shortwave U. V. light, becomes pink, but when exposed to daylight for a short time, again becomes white. In case 128.

* Statistician and Curator, California State Division of Mines.

21221 GARNET both green and red. Top of Greenhorn Mountain near Kernville. Donor: W. W. Travis. December 1945. In case 129.

21222 LEPIDOLITE (lithia mica) with albite. Chaffee County, Colorado, near Salida. Donor: P. D. Burtt. December 1945. In case 136.

21223 WOLLASTONITE ($CaSiO_3$). Calcium silicate, with colophonite garnet. Willsboro, Essex County, N. J. Donor: Mrs. R. Van L. Burnham. December 1945. In case 126.

21224 WOLLASTONITE ($CaSiO_3$). Calcium silicate. Carrizo Gorge in southeastern San Diego County, California. Donor: Mrs. R. Van L. Burnham. December 1945. In case 126.

REVIEW OF CALIFORNIA MINERAL PRODUCTION FOR 1945

By Henry H. Symons*

The total value of the mineral production of California for the year 1945 is conservatively estimated to be $488,244,000. This is partly detailed in the tabulation below, but there are more than sixty mineral substances on California's commercial list. Figures on the most important items only are available at this early date. The production report forms are being mailed to the operators in all mineral lines and the detailed and completed report will be compiled and published later.

The estimated total of $488,244,000 is an increase of approximately $18,470,000 over the 1944 total value of $469,774,525. The above total value for 1945 is the largest annual mineral output on record and is due to increased petroleum and natural gas yields.

The total petroleum output showed an increase of about 17,426,000 barrels or about 5.3% in amount, with almost a 5.2% increase in value over 1944. The estimated quantity of crude oil is 328,144,000 barrels for the year and is the largest annual production so far in California. Natural gas showed an increase in amount and value of about 16.4% due to increased yields of dry gas.

The gold output showed an increase over that of 1944 owing to a slight increase in dredging. Other metals to register an increase in output were silver, lead, and zinc but the amount of increased value will not offset the decrease in chromite, copper, manganese ore, quicksilver, and tungsten. The rescinding of War Production Board's order L-208 on July 1, 1945, and the taking off of all regulations on labor had little effect on the reopening of lode gold mines, but the filling of war demands with the resulting raising of specifications and lower prices had a definite effect on the output of such materials as chromite, manganese ore, quicksilver, and tungsten as most operations closed down.

There were mixed reactions regarding the structural materials and miscellaneous industrial minerals, but the demand for most materials under these headings remained good and both groups showed an increase in total value.

The saline group as a whole continued to show an increase in total value.

* Statistician and Curator, California State Division of Mines.

Estimated value and quantities for 1945 are as follows:

$6,023,000	(172,000 fine ounces) gold.
675,000	(949,000 fine ounces) silver.
1,878,000	(13,810,000 pounds) copper.
1,113,000	(12,940,000 pounds) lead.
2,055,000	(17,870,000 pounds) zinc.
2,918,000	(22,800 flasks) quicksilver.
6,200,000	Other metals, including chromite, iron ore, manganese ore, molybdenum ore, tungsten ore, etc.
347,832,000	(328,144,000 barrels) petroleum.
36,484,000	(543,000 M. cu. ft.) natural gas.
25,696,000	(17,600,000 barrels) cement.
23,500,000	Miscellaneous stone, including crushed rock, sand and gravel.
3,450,000	Brick and hollow building tile.
510,000	Other structural materials including bituminous rock, granite, magnesite, sandstone, and slate.
11,700,000	Miscellaneous industrial materials.
18,210,000	Salines including borates, iodine, potash, salt, soda, etc.
$488,244,000	Total value.

LIBRARY

LIBRARY REPORT

By James M. Little *

OUTLINE OF REPORT

INTRODUCTION

The library of the Division of Mines contains more than 6,000 selected volumes on mines, mining, and allied subjects. It is also the repository for reports and bulletins of technical departments of Federal and State governments and educational institutions both domestic and foreign. Current copies of newspapers published in the mining centers of the State are also available for reference.

The library and reading room are open to the public during the usual office hours, when the librarian may be freely called upon for all necessary assistance.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY AND UNITED STATES BUREAU OF MINES

The library of the Division of Mines has available for public reference the following publications of the United States Geological Survey: Annual Reports, Monographs, Professional Papers, Bulletins, Water-Supply Papers, Mineral Resources, Folios of the Geologic Atlas of the United States (broken file), Maps with Descriptive Text (broken file), Administrative Publications (broken file); and the following publications of the United States Bureau of Mines: Bulletins, Technical Papers, Economic Papers (broken file), Mineral Resources of the United States, Monographs (broken file), Reports of Investigations, Information Circulars.

Reports on California, recently received from the Survey and Bureau of Mines include:

United States Geological Survey

Water-Supply Papers
- No. 967-A, Notable Local Floods of 1939
  - Part 1, Floods of September 1939 in Colorado River Basin below Boulder Dam.
- No. 991, Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1943
  - Part 6, Southwestern States and Territory of Hawaii.

* Librarian, California State Division of Mines.

Maps with descriptions on file for reference
Tin Deposits of the Gorman District, Kern County, Calif.
Beryl Possibilities of the Pharlap Claims, Kern County, Calif.

United States Bureau of Mines

War Minerals Reports
445 Hogan Tin Mine, Kern County, Calif.
454 Oat Hill Mine, Napa County, Calif.

PUBLICATIONS OF STATE SURVEYS

A broken file of mining and geological publications, issued by the organizations listed below, may be consulted in the library of the Division of Mines.

Alabama Geological Survey, University.
Alaska (Territorial Commissioner of Mines), Juneau.
Arizona Bureau of Mines, Tucson.
Arkansas Geological Survey, Little Rock.
Colorado Bureau of Mines, Denver.
Connecticut Geological and Natural History Survey, Hartford.
Florida Department of Conservation, Tallahassee.
Georgia Division of Geology, Atlanta.
Idaho Bureau of Mines and Geology, Moscow.
Illinois Geological Survey, Urbana.
Indiana Division of Geology, Indianapolis.
Iowa Geological Survey, Des Moines.
State Geological Survey of Kansas, Lawrence.
Kentucky Geological Survey, Frankfort.
Louisiana Department of Conservation, New Orleans.
Maine State Geologist, Augusta.
Maryland Geological Survey, Baltimore.
Michigan Geological Survey, Lansing.
Minnesota Geological Survey, Minneapolis.
Mississippi State Geological Survey, University.
Missouri Bureau of Geology and Mines, Rolla.
Montana Bureau of Mines and Geology, Butte.
Nebraska Geological Survey, Lincoln.
Nevada State Bureau of Mines, Reno.
New Jersey Department of Conservation and Development, Trenton.
New Mexico Bureau of Mines and Mineral Resources, Socorro.
New York Science Division, Albany.
North Carolina Geological and Economic Survey, Chapel Hill.
North Dakota Geological Survey, Grand Forks.
Ohio Geological Survey, Columbus.
Oklahoma Geological Survey, Norman.
Oregon State Department of Geology and Mineral Industries, Portland.
Pennsylvania Topographic and Geological Survey, Harrisburg.
South Dakota State Geological Survey, Vermillion.
Tennessee Division of Geology, Nashville.
Texas Bureau of Economic Geology, Austin.
Virginia Geological Survey, University.
Washington State Department of Conservation and Development, Pullman.
West Virginia Geological Survey, Morgantown.
Wisconsin Geological and Natural History Survey, Madison.
Wyoming Geological Survey, Cheyenne.

PUBLICATIONS OF FOREIGN GOVERNMENTS

Publications of the following foreign governments are received and current issues may be consulted in the library. Earlier issues of foreign-language publications have been loaned to the California Academy of Sciences in Golden Gate Park, because of the limited storage space at the Division's offices in the Ferry Building. They may, however, be consulted at the Academy.

Alberta Research Council, Edmonton.
Argentina Direccion General de Minas y Geologica, Buenos Aires.
Brazil, Divisao de Geologica e Mineralogie, Rio de Janeiro.
Brazil, Ministry of Foreign Affairs, Rio de Janeiro.
British Columbia Minister of Mines, Victoria.
British Museum of Natural History, London.
Canada Department of Mines, Ottawa.
Cuerpo de Ingenieros de Minas del Peru, Lima.
Department of Scientific and Industrial Research, Wellington, N. Z.
Federated Malay States, Geological Survey, Kuala Lumpur.
Geological Service of Minas Geraes, Bella Harizonte, Brazil.
Geological Survey of Scotland.
Geological Survey, West Australia, Perth.

Gouvernment General de L'Afrique Equatoriale Francaise, Service des Mines, Brazzaville.
Gouvernment General de L'Afrique Occidentale Francaise, Service des Mines, Dakar.
Instituto Historica e Geographico, Rio de Janeiro.
Mexico, Universidad Nacional Autonoma de Mexico, Mexico, D. F.
Ministerio da Agricultura, Divisao de Geologia e Mineralogia, Rio de Janeiro.
Ministerio de Agricultura, Direccion de Minas y Geologia, Buenos Aires, Argentina.
Ministerio de Fomento y Obras Publicas, Lima, Peru.
Museo de Historia Natural de Montevideo, Uruguay.
Museu Nacional, Rio de Janeiro, Brazil.
New South Wales, Department of Mines, Sydney.
New Zealand Geological Survey Branch, Wellington.
Nova Scotia Department of Public Works and Mines, Halifax.
Ontario Department of Mines, Toronto, Canada.
Quebec Bureau of Mines, Quebec.
Queensland Department of Mines, Brisbane, Australia.
Queensland Government Mining Journal, Brisbane.
Republica Argentina, Direccion de Minas, Geologia e Hidrogeologia, Buenos Aires.
Royal Society of South Australia, Department of Mines, Adelaide.
Secretaria de la Economia Nacional, Direccion General de Minas y Petroleo, Mexico, D. F.
South Australia Department of Mines, Adelaide.
Universidad Nacional de Tucuman, Tucuman, Argentina.
Victoria, Department of Mines, Melbourne, Australia.
Western Australia Geological Survey, Perth.

PUBLICATIONS OF DOMESTIC SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academy of Natural Sciences of Philadelphia.
American Association of Petroleum Geologists, Tulsa, Oklahoma.
American Geographical Society of New York.
American Institute of Mining and Metallurgical Engineers, New York.
American Journal of Science, New Haven, Conn.
California Academy of Sciences, San Francisco.
Carnegie Institution of Washington.
Cleveland Museum of Natural History, Cleveland, Ohio.
Colorado College, Colorado Springs, Col.
Colorado School of Mines, Golden, Col.
Colorado Scientific Society, Denver.
Commonwealth Club, San Francisco.
Economic Geology, Lancaster, Pa.
Field Museum of Natural History, Chicago.
Franklin Institute, Lancaster, Pa.
Geological Society of America, Baltimore.
Journal of Geology, Chicago.
Journal of Paleontology, Chicago.
Mineralogical Society of America, Menasha, Wis.
Michigan College of Mining and Technology, Houghton.
Mining and Metallurgical Society of America, New York.
Missouri School of Mines and Metallurgy, Rolla.
National Research Council, Washington, D. C.
National Speleological Society, Washington, D. C.
New York Academy of Sciences, New York.
New York State Museum, Albany.
Pennsylvania State College, State College.
San Diego Society of Natural History, San Diego, California.
Santa Barbara Museum of Natural History, Santa Barbara, California.
Seismological Society of America, Stanford University.
Sierra Club, San Francisco.
Southern California Academy of Sciences, Los Angeles.
Stanford University, California.
University of California Publications in Engineering, Geography and Geology, Berkeley.
University of Harvard, Department of Mineralogy and Petrography, Cambridge, Mass.

PUBLICATIONS OF FOREIGN SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academia de Ciencias y Artes de Barcelona, Spain.
Australian Museum, Sydney.
Canadian Institute of Mining and Metallurgy, Montreal.
Chamber of Mines of West Australia, Kalgoorlie.
Geological Society of London.
Institution of Mining and Metallurgy, London.
Instituto Geologica de Mexico, Mexico, D. F.
Journal of the Royal College of Science, London.
Mexico Journal, Compilation and Translation Department, San Antonio, Texas.
Philippine Journal of Science, Manila.
Royal Society of South Australia, Adelaide.
Transvaal Chamber of Mines, Johannesburg.

CURRENT MAGAZINES

Current issues of the technical magazines listed below are on file in the reading room of the library, and may be consulted.

ADT Transmitted, New York.
Asbestos, Philadelphia.
Bakelite Review, New York.
Brick and Clay Record, Chicago.
California Highways and Public Works, Sacramento.
California Magazine of the Pacific, San Francisco.
California Mining Journal, Auburn.
California Oil World, Los Angeles.
California Safety News, San Francisco.
Canadian Mining Journal, Gardenvale, Quebec.
Chemical and Metallurgical Engineering, New York.
Chemical Industries, Philadelphia.
Deco Trefoil, Denver.
Desert Magazine, El Centro.
Du Pont Magazine, Wilmington, Del.
Driller, South Milwaukee.
Engineering and Mining Journal, New York.
Fairbanks-Morse News, Chicago.
Foote Prints, Philadelphia.
Fusion Facts, Whittier.
Gemmologist, London.
Grizzly Bear, Los Angeles.
Hercules Mixer, Wilmington, Del.
Highway Magazine, Middletown, Ohio.
Highway Traveller, Cleveland.
Independent Monthly, Tulsa, Oklahoma.
Johnson National Distillers Journal, St. Paul.
Light, Cleveland.
Light Metal Age, Chicago.
Lubrication, New York.
Marion Groundhog, Marion, Ohio.
Metals and Alloys, Pittsburgh, Pa.
Mineralogist, Portland, Ore.
Mines Magazine, Denver.
Mining and Contracting Review, Salt Lake City.
Mining and Geological Journal, Melbourne, Victoria, Australia.
Mining and Industrial News, San Francisco.
Mining and Metallurgy, New York.
Mining Congress Journal, Washington, D. C.
Mining Journal, Phoenix, Arizona.
Mining Journal, London.
Mining World, Seattle.
Nickel Steel Topics, New York.
Oil and Gas Journal, Tulsa, Oklahoma.
Oil, Paint and Drug Reporter, New York.
Oil Weekly, Houston, Texas.
Pacific Road Builder, San Francisco.
Pacific Purchaser, San Francisco.
Pay Dirt, Phoenix, Arizona.
Petroleum World, Los Angeles.
Pit and Quarry, Chicago.
Rock Products, Chicago .
Rocks and Minerals, Peekskill, N. Y.
Scientific American, New York.
Silicate, P's & Q's, Berkeley.
Standard Oil Bulletin, San Francisco.
Storage Battery Power, West Orange, N. J.

NEWSPAPERS

Current issues of the following papers are received and kept on file in the library:

Alaska Weekly, Seattle, Washington.
Amador Dispatch, Jackson, California.
Banner, Sonora, California.
Barstow Printer, Barstow, California.
Bridgeport Chronicle-Union, Bridgeport, California.
Calaveras Californian, Angels Camp, California.
Calaveras Prospect, San Andreas, California.
Daily Commercial News, San Francisco, California.
Del Norte Triplicate, Crescent City, California.
Denver Mining Record, Denver, Colorado.
Inyo Independent, Independence, California.
Inyo Register, Bishop, California.
Las Vegas Age, Las Vegas, Nevada.
Livermore Herald, Livermore, California.

Los Angeles Times, Los Angeles, California.
Mariposa Gazette, Mariposa, California.
Mining Press, Reno, Nevada.
Mohave Miner, Kingman, Arizona.
Morning Union, Grass Valley, California.
Mountain Messenger, Downieville, California.
Needles Nugget, Needles, California.
Oroville Mercury Register, Oroville, California.
Placer Herald, Auburn, California.
Placerville Times, Placerville, California.
Plumas Independent, Quincy, California.
Randsburg Times, Randsburg, California.
Tehachapi News, Tehachapi, California.
Terra Bella News, Terra Bella, California.
Tuolumne Independent, Sonora, California.
Tuolumne Prospector, Tuolumne, California.
Union Democrat, Sonora, California.
Weekly Trinity Journal, Weaverville, California.
Yreka Journal, Yreka, California.

SERVICES OF THE DIVISION OF MINES

The Division of Mines (formerly State Mining Bureau) is maintained for the purpose of assisting in all possible ways in the development of California's mineral resources.

As one means of offering tangible service to the mining public, the State Mineralogist for many years has issued an annual or a biennial report reviewing in detail the mines and mineral deposits of the various counties.

As a progressive step in advancing the interests of the mineral industry, and as permitting earlier distribution to the public, publication of the Annual Report of the State Mineralogist in the form of monthly chapters was begun in January 1922, and continued until March 1923. Owing to a lack of funds for printing this was changed to a quarterly publication, beginning in September 1923. For the same reason, beginning with the January 1924 issue, it became necessary to charge a subscription price. This covers approximately the cost of printing.

Pages are numbered consecutively throughout the year and an index to the complete report is included annually in the closing number.

Beginning with the 1930 issues, the activities and progress of the Geologic Branch are recorded also in these quarterly chapters. The important part that geology plays in the economic development of our mineral resources is further recognized in the change of title from *Mining in California* to CALIFORNIA JOURNAL OF MINES AND GEOLOGY, beginning with the January 1933 chapter.

While current activities of all descriptions are covered in these chapters, the practice of issuing from time to time technical reports on special subjects will be continued as well. A list of such reports now available is appended hereto, and the names of new bulletins will be added in the future as they are completed.

The chapters are subject to revision, correction and improvement. Constructive suggestions from the mining public will be gladly received, and are invited.

The one aim of the Division of Mines is to increase its usefulness and to stimulate the intelligent development of the wonderful, latent resources of the State of California.

TYPES OF REPORTS

In general the reports presented in these chapters are grouped into three classes:

1. Mines and mineral resources of a given county or area (describing kind, character, distribution and extent of development).

2. Specific economic and industrial mineral products (listing and describing the resources over the entire State of a given mineral substance, e.g., feldspar).

3. Geological reports on specific areas (recording results and conclusions with maps, derived from field studies; and tied in with economic possibilities and developments).

Reports of District Mining Engineers

In 1919-1920 the Mining Bureau was organized into four main geographical divisions, with the field work delegated to a mining engineer in each district, working out from field offices that were established in Redding, Auburn, San Francisco and Los Angeles, respectively. This move brought the office into closer personal contact with operators, and it has many advantages over former methods of conducting field work, including lower traveling-expense bills for the Bureau's engineers. In 1923 the Redding and Auburn field offices were consolidated and moved to Sacramento.

The Redding office was reestablished in 1928, and the boundaries of each district adjusted. The counties now included in each of the four divisions and the locations of the branch offices are shown on the frontispiece outline map of the State.

Reports of mining activities and development in each district, prepared by the District Engineer, will continue to appear under the proper field division heading.

Special Articles

Detailed technical reports on special subjects, the result of research work or extended field investigations, will continue to be issued as separate bulletins by the Division, as has been the custom in the past.

Shorter and less elaborate technical papers and articles by members of the staff and others are published in each number of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

These special articles cover a wide range of subjects both of historical and current interest; descriptions of new processes, or metallurgical and industrial plants, new mineral occurrences, and interesting geological formations, as well as articles intended to supply practical and timely information on the problems of the prospector and miner, such as the text of new laws and official regulations and notices affecting the mineral industry.

MAIL AND FILES

The Division of Mines maintains, in addition to its correspondence files and the library, a mine file which includes original reports on the various mines and mineral properties of all kinds in California.

During each quarterly period there are several thousand letters received and answered at the San Francisco office alone, covering almost every phase of prospecting, mining and developing mineral deposits, reduction problems, marketing of refined products and mining law. In addition to this, hundreds of oral questions are answered daily, both at the main office and the district offices, for the many inquirers who come in for personal interviews and to consult the files and library.

The library has a card-file system for references to individual California mines, occurring in the publications of the Division of Mines, in the Mining and Scientific Press, the Engineering and Mining Journal, and the Arizona Mining Journal.

COMMERCIAL MINERAL NOTES

The producer and consumer of mineral products are mutually dependent upon each other for their prosperity, and one of the most direct aids rendered by this Division to the mining industry in the past

has been that of bringing producers and consumers into direct touch with each other.

This work has been carried on largely by correspondence, supplemented by personal consultation. Lists of buyers of all the commercial minerals produced in California have been made available to producers upon request, and likewise the owners of undeveloped deposits of various minerals, and producers of them, have been made known to those looking for raw mineral products.

When the publication of *Mining in California* was on a monthly basis, current inquiries from buyers and sellers were summarized and lists of mineral products or deposits 'wanted' or 'for sale' included in each issue.

It is important that inquiries of this nature reach the mining public as soon as possible and in order to avoid the delay incident to the present quarterly publication of CALIFORNIA JOURNAL OF MINES AND GEOLOGY, these lists are now issued monthly in the form of a mimeographed sheet under the title of *Commercial Mineral Notes,* and sent to those on the mailing list of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

EMPLOYMENT SERVICE

Following the establishment of the Mining Division branch offices in 1919, a free technical employment service was offered as a mutual aid to mine operators and technical men for the general benefit of the mineral industry.

Briefly summarized, men desiring positions are registered, the cards containing an outline of the applicant's qualifications, position wanted, salary desired, etc., and as notices of 'positions open' are received, the names and addresses of all applicants deemed qualified are sent to the prospective employer for direct negotiations.

Telephone and telegraphic communications are also given immediate attention.

Technical men, or those qualified for supervisory positions, and vacancies of like nature only, are registered, as no attempt will be made to supply mine and mill labor.

Registration cards for the use of both prospective employers and employees may be obtained upon request, and a cordial invitation is extended to the industry to make free use of the facilities afforded. Parties interested should communicate direct with our San Francisco office.

DETERMINATION OF MINERAL SAMPLES

Samples (limited to two in one month) of any mineral found in the State may be sent to the Division of Mines for identification, and the same will be classified free of charge. No samples will be determined if received from points outside the State. It must be understood that no assays, or quantitative determinations will be made. Samples should be in lump form if possible, and marked plainly with name of sender on outside of package, etc. No samples will be received unless delivery charges are prepaid. A letter should accompany sample, giving locality where mineral was found and the nature of the information desired.

PUBLICATIONS OF THE DIVISION OF MINES

During the past sixty-five years, in carrying out the provisions of the organic act creating the former California State Mining Bureau, there have been published many reports, bulletins and maps which go to make up a library of detailed information on the mineral industry of the State, a large part of which could not be duplicated from any other source.

One feature that has added to the popularity of the publications is that many of them have been distributed without cost to the public, and even the more elaborate ones have been sold at a price which barely covers the cost of printing.

Owing to the fact that funds for the advancing of the work of this department have usually been limited, the reports and bulletins mentioned are printed in limited editions many of which are now entirely exhausted.

Copies of such publications are available for reference, however, in the offices of the Division of Mines, in the Ferry Building, San Francisco 11; State Building, Los Angeles 12; State Office Building No. 1, Sacramento 14; Redding; and Division of Oil and Gas at Santa Barbara, Santa Paula, Taft, Bakersfield, Coalinga. They may also be found in many public, private and technical libraries in California and other states and foreign countries.

A catalog of all publications from 1880 to 1917, giving a synopsis of their contents, is issued as Bulletin No. 77.

Publications in stock may be obtained postpaid by addressing the San Francisco, Los Angeles or Sacramento offices and enclosing the requisite amount.

Remittances of stamps in an amount not to exceed 26 cents, currency or coin will be accepted at sender's risk. Payment is preferred in the form of money orders.

Money orders should be made payable to the Division of Mines.

Write for latest revised price list.

NOTE.—The Division of Mines frequently receives requests for some of the early Reports and Bulletins now out of print, and it will be appreciated if parties having such publications and wishing to dispose of them will advise this office.

REPORTS

Asterisks (**) indicate the publication is out of print.

	Price (including postage and sales tax)
**Report I of the State Mineralogist, 1880, 43 pp. Henry G. Hanks	----
**Report II of the State Mineralogist, 1882, 514 pp., 4 illustrations, 1 map. Henry G. Hanks	----
**Report III of the State Mineralogist, 1883, 111 pp., 21 illustrations. Henry G. Hanks	----
**Report IV of the State Mineralogist, 1884, 410 pp., 7 illustrations. Henry G. Hanks	----
**Report V of the State Mineralogist, 1885, 234 pp., 15 illustrations, 1 geological map. Henry G. Hanks	----
**Report VI of the State Mineralogist, Part 1, 1886, 145 pp., 3 illustrations, 1 map. Henry G. Hanks	----
Part II, 1887, 222 pp., 36 illustrations. William Irelan, Jr. Price $0.75, sales tax $0.02	$0.77
**Report VII of the State Mineralogist, 1887, 315 pp. William Irelan, Jr.	----
**Report VIII of the State Mineralogist, 1888, 948 pp., 122 illustrations. William Irelan, Jr.	----
Report IX of the State Mineralogist, 1889, 352 pp., 57 illustrations, 2 maps. William Irelan, Jr. Price $1.15, sales tax $0.03	1.18
**Report X of the State Mineralogist, 1890, 983 pp., 179 illustrations, 10 maps. William Irelan, Jr.	----
Report XI (First Biennial) of the State Mineralogist, for the two years ending September 15, 1892, 612 pp., 73 illustrations, 4 maps. William Irelan, Jr. Price $1.50, sales tax $0.04	1.54
**Report XII (Second Biennial) of the State Mineralogist, for the two years ending September 15, 1894, 541 pp., 101 illustrations, 5 maps. J. J. Crawford	----
**Report XIII (Third Biennial) of the State Mineralogist, for the two years ending September 15, 1896, 726 pp., 93 illustrations, 1 map. J. J. Crawford	----
Chapters of the State Mineralogist's Report XIV, Biennial Period, 1913-1914, Fletcher Hamilton:	
**Mines and Mineral Resources, Amador, Calaveras and Tuolumne Counties, 172 pp., paper	----
Mines and Mineral Resources, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma and Yolo Counties, 208 pp., paper. Price $0.50, sales tax $0.01	.51
Mines and Mineral Resources, Del Norte, Humboldt and Mendocino Counties, 59 pp., paper. Price $0.35, sales tax $0.01	.36
Mines and Mineral Resources, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin and Stanislaus Counties, 220 pp., paper. Price $0.75, sales tax $0.02	.77
Mines and Mineral Resources of Imperial and San Diego Counties, 113 pp., paper. Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, Shasta, Siskiyou and Trinity Counties, 180 pp., paper	----
**Report XIV of the State Mineralogist, for the Biennial Period 1913-1914, Fletcher Hamilton, 1915: A General Report on the Mines and Mineral Resources of Amador, Calaveras, Tuolumne, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma, Yolo, Del Norte, Humboldt, Mendocino, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, San Diego, Imperial, Shasta, Siskiyou and Trinity Counties, 974 pp., 275 illustrations, cloth	----
Chapters of the State Mineralogist's Report XV, Biennial Period, 1915-1916, Fletcher Hamilton:	
**Mines and Mineral Resources, Alpine, Inyo and Mono Counties, 176 pp., paper	----
Mines and Mineral Resources, Butte, Lassen, Modoc, Sutter and Tehama Counties, 91 pp., paper. Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, El Dorado, Placer, Sacramento and Yuba Counties, 198 pp., paper	----

REPORTS—Continued

Asterisks (**) indicate the publication is out of print.	Price (including postage and sales tax)
**Mines and Mineral Resources, Monterey, San Benito, San Luis Obispo, Santa Barbara and Ventura Counties, 183 pp., paper	----
**Mines and Mineral Resources, Los Angeles, Orange and Riverside Counties, 136 pp., paper	----
**Mines and Mineral Resources, San Bernardino and Tulare Counties, 186 pp., paper	----
**Report XV of the State Mineralogist, for the Biennial Period 1915-1916, Fletcher Hamilton, 1917: A General Report on the Mines and Mineral Resources of Alpine, Inyo, Mono, Butte, Lassen, Modoc, Sutter, Tehama, Placer, Sacramento, Yuba, Los Angeles, Orange, Riverside, San Benito, San Luis Obispo, Santa Barbara, Ventura, San Bernardino and Tulare Counties, 990 pp., 413 illustrations, cloth	----
Chapters of the State Mineralogist's Report XVI, Biennial Period, 1917-1918, Fletcher Hamilton:	
**Mines and Mineral Resources of Nevada County, 270 pp., paper	----
Mines and Mineral Resources of Plumas County, 188 pp., paper Price $0.50, sales tax $0.01	$0.51
Mines and Mineral Resources of Sierra County, 144 pp., paper Price $0.75, sales tax $0.02	.77
Report XVII of the State Mineralogist, 1920, 'Mining in California during 1920,' Fletcher Hamilton; 562 pp., 71 illustrations, cloth Price $2.50, sales tax $0.06	2.56
Report XVIII of the State Mineralogist, 1922, 'Mining in California,' Fletcher Hamilton. Chapters published monthly beginning with January, 1922:	
**January, **February, **March, April, May, June, July, August, September, October, November, December, 1922 Price $0.30, sales tax $0.01	.31
Chapters of Report XIX of the State Mineralogist, 'Mining in California,' Fletcher Hamilton and Lloyd L. Root. January, February, March, September, 1923 Price $0.30, sales tax $0.01	.31
Chapters of Report XX of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly. January, April,** July, October, 1924, per copy Price $0.30, sales tax $0.01	.31
Chapters of Report XXI of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1925. Mines and Mineral Resources of Sacramento, Monterey and Orange Counties Price $0.30, sales tax $0.01	.31
**April, 1925. Mines and Mineral Resources of Calaveras, Merced, San Joaquin, Stanislaus and Ventura Counties	----
**July, 1925. Mines and Mineral Resources of Del Norte, Humboldt and San Diego Counties	----
**October, 1925. Mines and Mineral Resources of Siskiyou, San Luis Obispo and Santa Barbara Counties	----
Chapters of Report XXII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
**January, 1926. Mines and Mineral Resources of Trinity and Santa Cruz Counties	----
**April, 1926. Mines and Mineral Resources of Shasta, San Benito and Imperial Counties	----
July, 1926. Mines and Mineral Resources of Marin and Sonoma Counties Price $0.30, sales tax $0.01	.31
**October, 1926. Mines and Mineral Resources of El Dorado and Inyo Counties, also report on Minaret District, Madera County	----
Chapters of Report XXIII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1927. Mines and Mineral Resources of Contra Costa County; Santa Catalina Island Price $0.30, sales tax $0.01	.31

REPORTS—Continued

Asterisks (**) indicate the publication is out of print. Price (including postage and sales tax)

April, 1927. Mines and Mineral Resources of Amador and Solano Counties Price $0.30, sales tax $0.01 $0.31

**July, 1927. Mines and Mineral Resources of Placer and Los Angeles Counties -- --

October, 1927. Mines and Mineral Resources of Mono County Price $0.30, sales tax $0.01 .31

Chapters of Report XXIV of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:

January, 1928. Mines and Mineral Resources of Tuolumne County Price $0.30, sales tax $0.01 .31

April, 1928. Mines and Mineral Resources of Mariposa County Price $0.30, sales tax $0.01 .31

**July, 1928. Mines and Mineral Resources of Butte and Tehama Counties ----

October, 1928. Mines and Mineral Resources of Plumas and Madera Counties Price $0.30, sales tax $0.01 .31

Chapters of Report XXV of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:

**January, 1929. Mines and Mineral Resources of Lassen, Modoc and Kern Counties; also on Special Placer Machines ----

**April, 1929. Mines and Mineral Resources of Sierra, Napa, San Francisco and San Mateo Counties ----

July, 1929. Mines and Mineral Resources of Colusa, Fresno and Lake Counties Price $0.30, sales tax $0.01 .31

October, 1929. Mines and Mineral Resources of Glenn, Alameda, Mendocino and Riverside Counties Price $0.30, sales tax $0.01 .31

Chapters of Report XXVI of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:

January, 1930. Mines and Mineral Resources of Santa Clara County; also Barite in California Price $0.40, sales tax $0.01 .41

**April, 1930. Mines and Mineral Resources of Nevada County; also Mineral Paint Materials in California ----

**July, 1930. Mines and Mineral Resources of Yuba and San Bernardino Counties; also Commercial Grinding Plants in California ----

October, 1930. Mines and Mineral Resources of Butte, Kings and Tulare Counties; also Geology of Southwestern Mono County (Preliminary) Price $0.40, sales tax $0.01 .41

Chapters of Report XXVII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:

January, 1931. Preliminary Report of Economic Geology of the Shasta Quadrangle. Beryllium and Beryl. The New Tariff and Nonmetallic Products. Crystalline talc. Decorative effects in Concrete Price $0.40, sales tax $0.01 .41

April, 1931. Stratigraphy of the Kreyenhagen Shale. Diatoms and Silicoflagellates of the Kreyenhagen Shale. Foraminifera of the Kreyenhagen Shale. Geology of Santa Cruz Island Price $0.40, sales tax $0.01 .41

**July, 1931. (Yuba, San Bernardino Counties.) Feldspar, Silica, Andalusite and Cyanite Deposits of California. Note on a Deposit of Andalusite in Mono County; its occurrence and chemical importance. Bill creating Trinity and Klamath River Fish and Game District and its effect upon mining ----

October, 1931. (Alpine County.) Geology of the San Jacinto Quadrangle south of San Gorgonio Pass, California. Notes on Mining Activities in Inyo and Mono Counties in July, 1931 Price $0.40, sales tax $0.01 .41

Chapters of Report XXVIII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:

January, 1932, Economic Mineral Deposits of the San Jacinto Quadrangle. Geology and Physical Properties of Building Stone from Carmel Valley. Contributions to the Study of Sediments. Sediments of Monterey Bay. Sanbornite Price $0.40, sales tax $0.01 .41

REPORTS—Continued

Asterisks (**) indicate the publication is out of print. Price (including postage and sales tax)

**April, 1932. Elementary Placer Mining Methods and Gold Saving Devices. The Pan, Rocker and Sluice Box. Prospecting for Vein Deposits. Bibliography of Placer Mining---- ----

**Abstract from April quarterly; Elementary Placer Mining Methods and Gold Saving Devices. Types of Deposits, Simple Equipment. Special Machines. Dry Washing. Black Sand Treatment. Marketing of Products. Placer Mining Areas. Laws. Prospecting for Quartz Veins. Bibliography (mimeographed)---- ----

**July-October, 1932. (Ventura County). Report accompanying Geologic Map of Northern Sierra Nevada. Fossil Plants in Auriferous Gravels of the Sierra Nevada. Glacial and Associated Stream Deposits of the Sierra Nevada. Jurassic and Cretaceous Divisions in the Knoxville Shasta Succession of California. Geology of a part of the Panamint Range. Economic Report of a Part of the Panamint Range. Acquiring Mining Claims Through Tax Title. The Biennial Report of State Mineralogist---- ----

Chapters of Report XXIX, 1933 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

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**Map of Madera County, Showing Boundaries, National Forests	----
**Map of Placer County, Showing Boundaries, National Forests	----
**Map of Sierra County, Showing Boundaries, National Forests	----
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**Map of Plumas County	----
**Map of Trinity County	----
**Map of Tuolumne County	----
**Geographical Map of Inyo County. Scale 1 inch equals 4 miles	----
**Map of California accompanying Bulletin No. 89, showing generalized classification of land with regard to oil possibilities. Map only, without Bulletin	----
**Geologic Map of California, 1916. Scale 1 inch equals 12 miles. Shows railroads, highways, post offices and other towns. Geological details lithographed in 23 colors. Mounted	----
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San Bernardino County Map, accompanying report on mines and mineral resources of San Bernardino County in October, 1943, Chapter of Report XXXIX, sold separately Price $0.15, sales tax $0.01	.16
Manganese Deposits (showing California geology uncolored), accompanying Bulletin 125, sold separately Price $0.60, sales tax $0.02	.62
Jamesburg Quadrangle Geologic Map and Structure Section, accompanying report on geology of area in April 1944 Chapter of Report XL, sold separately Price per set $0.40, sales tax $0.01	.41

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WALTER W. BRADLEY State Mineralogist

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CONTENTS

PLATES

INDEX MAP
OF
ECONOMIC MINERALS
IN
CALIFORNIA
AND THE
DISTRICTS OF THE DIVISION OF MINES
SCALE
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CALIFORNIA STATE DIVISION OF MINES
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DISTRICT OFFICES OF THE DIVISION OF MINES
San Francisco (main office)
Los Angeles
Sacramento
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BOUNDARIES OF THE DISTRICTS
OREGON
NEVADA
REDDING
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SAN FRANCISCO
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
GLENN
BUTTE
SIERRA
NEVADA
YUBA
PLACER
LAKE
COLUSA
SUTTER
EL DORADO
YOLO
SONOMA
NAPA
SOLANO
AMADOR
ALPINE
CALAVERAS
MARIN
SACRAMENTO
SAN JOAQUIN
CONTRA COSTA
TUOLUMNE
MONO
ALAMEDA
SAN MATEO
STANISLAUS
MARIPOSA
124°
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116°
115°
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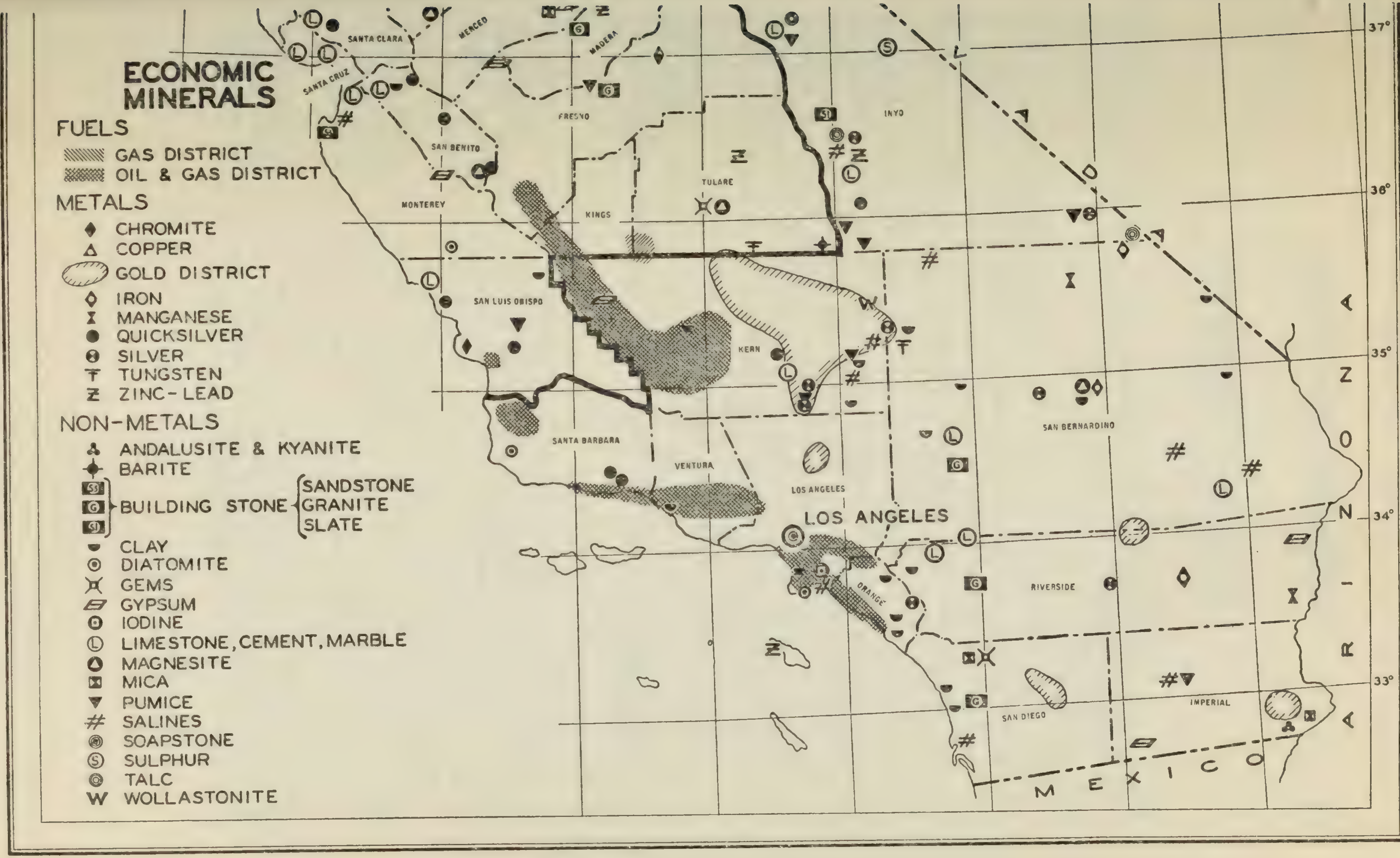
ECONOMIC MINERALS
FUELS
GAS DISTRICT
OIL & GAS DISTRICT
METALS
CHROMITE
COPPER
GOLD DISTRICT
IRON
MANGANESE
QUICKSILVER
SILVER
TUNGSTEN
ZINC-LEAD
NON-METALS
ANDALUSITE & KYANITE
BARITE
BUILDING STONE
SANDSTONE
GRANITE
SLATE
CLAY
DIATOMITE
GEMS
GYPSUM
IODINE
LIMESTONE, CEMENT, MARBLE
MAGNESITE
MICA
PUMICE
SALINES
SOAPSTONE
SULPHUR
TALC
WOLLASTONITE
SANTA CLARA
SANTA CRUZ
MERCED
MADERA
FRESNO
SAN BENITO
MONTEREY
KINGS
TULARE
INYO
SAN LUIS OBISPO
KERN
SANTA BARBARA
VENTURA
LOS ANGELES
LOS ANGELES
SAN BERNARDINO
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
NEVADA
ARIZONA
MEXICO
37°
36°
35°
34°
33°

ADMINISTRATION

ADMINISTRATIVE REPORT

By Walter W. Bradley, State Mineralogist

Personnel

There have been no changes in personnel to be noted during the past three months.

Federal Cooperation

In February, the State Mineralogist conferred in Washington, D. C., with the Director, Dr. William E. Wrather, and staff members of the U. S. Geological Survey concerning the cooperative program on geological work in California. Most satisfactory progress is being made. Contact was also made with certain members of California's delegation in Congress and members of the Home Committee on Appropriations advising them of the value and need for adequate support to the U. S. Geological Survey for both geological field work and topographic mapping, as California had already appropriated specific sums of money for these projects on the premise that they will be matched by the federal agency. The Director and staff members of the U. S. Bureau of Mines were also contacted relative to activities in California.

At Urbana, Illinois, February 21-23, inclusive, the annual meeting of the American Association of State Geologists was attended, where the members were the guests of Dr. M. M. Leighton, State Geologist of Illinois, and his staff.

New Publications

CALIFORNIA JOURNAL OF MINES AND GEOLOGY
April 1945, being Chapter 2 of State Mineralogist's Report XLI. This chapter contains: *Quicksilver Deposits of the Knoxville District, Napa, Yolo, and Lake Counties*, with maps; *Unexpected Use Transforms Outlook for Quicksilver; Steel; Mineral Statistics for 1944; Accessions to the Exhibit; Library Report.*

CALIFORNIA JOURNAL OF MINES AND GEOLOGY
July 1945, being Chapter 3 of State Mineralogist's Report XLI. This chapter contains: *Administrative Report; Current Notes of Geologic Branch; Mineral Resources of Riverside County*, with map; *Recent Legislation Affecting Mining; California Mineral Production for 1944; Accessions to the Exhibit; Carbon*, also *Fluorspar* (papers on Commercial Minerals); *Library Report.*

BULLETIN 132, CALIFORNIA MINERAL PRODUCTION AND DIRECTORY OF MINERAL PRODUCERS FOR 1944, by Henry H. Symons, statistician; 224 pages, 8 illustrations. This is the complete detailed report by substances and counties of the mineral production for the year 1944.

GEOLOGIC BRANCH

CURRENT NOTES

By Olaf P. Jenkins*

Two quicksilver reports are published in this issue of the *Journal:* (1) *Quicksilver Deposits of the New Idria District, San Benito and Fresno Counties, California,* by Edwin B. Eckel and W. B. Myers; and (2) *Quicksilver Deposits at the Sulphur Bank Mine, Lake County, California,* by Donald L. Everhart.

Recently the Division of Mines has published the following: (1) *Quicksilver Deposits of Central San Benito and Northwestern Fresno Counties, California,* by Robert G. Yates and Lowell S. Hilpert, California Journal of Mines and Geology for January, 1945, pp. 11-35, 3 figs., 5 pls.; and *Quicksilver Deposits of the Knoxville District, Napa, Yolo, and Lake Counties, California,* by Paul Averitt, California Journal of Mines and Geology for April, 1945, pp. 65-89, 2 figs., pls. 6-14.

Two other quicksilver reports are in press in the California Journal of Mines and Geology for July, 1946: (1) *Quicksilver Deposits of the Western Mayacmas District, Sonoma County, California,* by Edgar H. Bailey; and (2) *Quicksilver Deposits of Eastern Mayacmas District, Lake and Napa Counties, California,* by Robert G. Yates and Lowell S. Hilpert.

In addition to these reports, all of which represent results of the strategic minerals investigation of the U. S. Geological Survey, will be issued in the not-too-distant future a geological report on the New Almaden quicksilver district.

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* Chief Geologist, California State Division of Mines.

QUICKSILVER DEPOSITS OF THE NEW IDRIA DISTRICT SAN BENITO AND FRESNO COUNTIES, CALIFORNIA*

By EDWIN B. ECKEL** and W. B. MYERS***
UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY

OUTLINE OF REPORT

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication January 2, 1946.
** Geologist, U. S. Geological Survey.
*** Geologist, U. S. Geological Survey.

FIG. 1. Index map of San Benito and adjoining counties, California, showing location of the New Idria district.

ABSTRACT

The New Idria district, third in all-time production among North American quicksilver mining districts, lies in the rugged Diablo Range, 140 miles southeast of San Francisco. The New Idria mine was discovered in 1853 and, except for 1921-22, has been in continuous production ever since. Nearly 20 other deposits have been found but of these only the San Carlos has yielded a large amount of quicksilver. Between 1858 and 1944 the district produced 437,195 flasks of quicksilver, valued at about 31 million dollars.

The mapped area of about 135 square miles consists of a large oval body of strongly sheared serpentine, rimmed by sandstone of the Franciscan group and by the Upper Cretaceous Panoche formation and later sediments. The structure is that of an asymmetric anticlinal dome, marked on its northeast flank by overturned beds and by an irregular thrust fault, here termed the New Idria thrust fault, along the Franciscan-Panoche contact. On other sides of the dome the contacts between Panoche and older rocks are steeply dipping faults, which encircle the core and commonly dip away from it. The origin of the dome and of the faults is thought to be closely related to the emplacement of the serpentine mass, which has moved upward intermittently since pre-Panoche time.

The quicksilver deposits consist predominantly of cinnabar as veins and stockworks that occupy fractures in altered rocks. The ones of greatest commercial importance, including the New Idria and San Carlos, lie in hydrothermally indurated beds of the Panoche formation beneath the New Idria thrust fault and associated tear faults which offset the thrust. Both rock alteration and ore deposition were localized primarily at abrupt changes in strike of the fault plane, though changes in dip were also locally important in controlling some of the ore shoots and deposits. Several minor deposits lie in altered Panoche rocks above the normal faults on the south side and below the reverse fault on the west side of the dome and still others occur in silica-carbonate rock derived from serpentine.

INTRODUCTION

The highly productive New Idria quicksilver district in southern San Benito County and western Fresno County, is in the southern part of the Diablo Range of the California Coast Ranges. It is about 140 miles southeast of San Francisco and 55 miles southwest of Fresno (see fig. 1). All the deposits described here, foremost of which is that of the New Idria mine, lie within a rectangular area that is about 15 miles long by 9 miles wide (see pl. 8).

Despite its central location, the district is actually one of the more isolated of California mining camps. Idria, all of whose 400 population are dependent on the New Idria mine, is the only town in the district. Tres Pinos, the nearest shipping point on the Southern Pacific Railway, and Hollister, the principal supply town, are 60 and 67 miles northwest of Idria. The mountainous connecting roads are fair to good during the greater part of the year but high water in numerous fords often necessitates long detours during the rainy winter months. Coalinga and King City (fig. 1) are the chief supply towns for the southern and western parts. Most of the mines are served by fair dirt roads but except for those near the New Idria mine, few of these are open to travel during the winter.

This part of the Diablo Range consists of moderately rugged mountains, with several peaks over 5,000 feet in altitude, and with a total relief in the mapped area of more than 3,000 feet. The western and much of the central parts are drained by the San Benito River and its tributaries. The rest of the district is drained by various tributaries of the San Joaquin River. Some of the larger streams are perennial but even these are apt to cease flowing in unusually dry years. The potable but very "hard" water supply for Idria is piped from a small reservoir

on San Carlos Creek near the Aurora mine. Water for other mines comes from springs or springfed streams.

Plates 10 and 11 are typical views of the district's vegetation. Most of the higher, central part, which is underlain by serpentine, is relatively bare except for scattered stands of pine and cedar, the remnants of much heavier timber that has been cut during the past 80 years for mining purposes. Other parts of the district are covered by brush of various kinds, much of it in impenetrable thickets, many acres in extent. Oak for retort fuel is available locally but all lumber and nearly all mine timbers are imported.

About 5 months were devoted to the original field work, which began in mid-September 1940 and continued with interruptions through May 1941. Completion of this part of the project was made possible only by the wholehearted and very able help and cooperation of R. G. Yates, R. A. Brown, and A. E. Bradbury, each of whom worked on it for periods of 6 weeks to 3 months.

From late November 1941 until June 1942 W. B. Myers was in the district as the Survey representative of a joint Federal Geological Survey-Federal Bureau of Mines drilling program in the New Idria-San Carlos area. Further detailed maps of the surface in this area and of the continuing underground developments in the eastern part of the New Idria mine were prepared during this time. Between June 1942 and October 1943 Mr. Myers returned to the district on three occasions for periods of 3 to 7 days and mapped new underground workings in the New Idria mine with the guidance and assistance of J. McLaren Forbes, company geologist. New workings in the Del Mexico mine were also mapped and a sketch map was drawn of the surface and workings at the Anita mine. On many occasions since June 1942, Mr. Forbes very kindly forwarded geologic maps of new workings and descriptions of progress; much of this material has been incorporated in the illustrations and text of this report. The illustrations in the report may be considered to be up to date as of October 1943, although some stope data as recent as December 1943 have been incorporated.

The geology of the ore deposits has been described by numerous writers, including Becker,[1] Lake,[2] and Schuette.[3] Their descriptions were consulted frequently during this investigation and their maps form the basis of parts of some of the maps in this report. It was not possible, however, to reconcile all their beliefs with evidence available in 1943.

The area studied is shown on the Idria topographic quadrangle, published by the Geological Survey on a scale of 1:62,500. Copies of the topographers' 1940 field sheets on a 1:48,000 scale were used for mapping the areal geology, providing a far better base for detailed studies than was available to previous investigators.

All the operators in the district aided the work in every possible manner. For cordial hospitality and cooperation that is outstanding even in the proverbially hospitable mining fraternity, thanks are due the New Idria Quicksilver Mining Company and its staff, especially to

[1] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Monograph 13, pp. 301-309, 379-381, 1888.

[2] Lake, M. C., Geologic maps of the New Idria mine, with brief description of the geology: Unpublished report, on file at office of New Idria Quicksilver Mining Co., Idria, Calif., 1929.

[3] Schuette, C. N., Occurrence of quicksilver orebodies: Trans. Am. Inst. Min. Engrs., Tech. Pub. 335, 87 pp., 1931.

H. W. Gould, general manager, C. H. Lewis, superintendent, and J. McLaren Forbes, geologist. D. F. Ferris' painstaking work in compiling production statistics was made fruitful through the cooperation of W. W. Bradley, state mineralogist, and H. H. Symons, statistician, of the California Division of Mines. Among those who visited the writers in the field and who contributed helpful suggestions and encouragement were D. F. Hewett and H. G. Ferguson of the Federal Geological Survey, Olaf P. Jenkins, Chief Geologist, State Division of Mines, and N. L. Taliaferro of the University of California.

HISTORY AND PRODUCTION

The New Idria quicksilver deposit, destined to become second to New Almaden among North American quicksilver producers, was discovered about 1853 by two Mexican prospectors who had first explored a small body of chromite near the present Aurora mine in the belief that it was silver ore. They also mistook the cinnabar in the New Idria outcrops for a silver mineral, but its true identity was soon learned and the first quicksilver was produced in 1854, though not by the original discoverers. The early history of the district is clouded by poor records and by a series of legal and other difficulties, some of which led to bloodshed. Bret Harte describes these difficulties in an interesting and basically accurate fashion.[4] Essentials of the mining and metallurgical history as given by Forstner and Bradley are brought up to date by Ransome and Kellogg.[5]

Beginning with the New Idria and Aurora in 1853, nearly a score of deposits were discovered at intervals during the ensuing 80 years. Except for the New Idria and the San Carlos, none of these have ever become large or steady producers. Magnesite,[6] chromite, and the gem mineral benitoite,[7] have also been produced but not in quantity or value comparable to quicksilver.

Between 1850 and 1940, California mines produced more than 2,400,000 flasks of quicksilver, worth about $117,000,000. During the same period, the New Idria district produced 396,443 flasks, worth nearly $24,000,000, placing the New Idria district third and the New Idria mine second among California districts and mines.

The recorded production for each year is shown in the accompanying table. Unfortunately the quicksilver produced by other mines in the district prior to 1900 has been credited to the New Idria mine or has not been recorded. Even so, it is plain that the New Idria mine has been responsible for more than 98 percent of the district's production.

The New Idria mine is notable not only for its large total production but for its nearly unbroken record of production for a period of almost 90 years. Except for 1921 and 1922, when a fire destroyed the plant and caused a shutdown, the mine has produced continuously since before

[4] Harte, Bret, The story of a mine.

[5] Forstner, William, The quicksilver resources of California: California State Min. Bur. Bull. 27, pp. 125-147, 1903. Bradley, W. W., Quicksilver resources of California: California State Min. Bur. Bull. 78, pp. 93-122, 1918. Ransome, A. L., and Kellogg, J. L., Quicksilver resources of California: California Jour. Mines and Geology, vol. 35, pp. 376-378 and 416-430, 1939 (1940).

[6] Gale, H. S., Late developments of magnesite deposits in California and Nevada: U. S. Geol. Survey Bull. 540, pp. 503-509, 1912. Bradley, W. W., Magnesite in California: California State Min. Bur. Bull. 79, p. 147, 1926.

[7] Louderback, G. D., Benitoite, a new California gem mineral: Univ. California, Bull. Dept. Geol. Sci., vol. 5, no. 9, pp. 149-153, 1907. Benitoite, its paragenasis and mode of occurrence: California Univ., Bull. Dept. Geol. Sci., vol. 5, no. 23, pp. 351-380, 1909.

Recorded production of quicksilver, New Idria district, 1858-1944 [1]

Year	New Idria mine [2] Flasks [3]	All other mines [4] Flasks [3]	Year	New Idria mine [2] Flasks [3]	All other mines [4] Flasks [3]
1858-65, incl.	17,455 [5]	----	1906	7,200	3
1866	6,525	----	1907	7,675	10
1867	11,493	----	1908	9,600	10
1868	12,180	----	1909	8,900	
1869	10,315	----	1910	10,800	4
1870	9,888	----	1911	9,750	79
1871	8,180	----	1912	9,600	154
1872	8,171	----	1913	9,700	20
1873	7,735	----	1914	6,550	90
1874	6,911	----	1915	6,250	75
1875	8,432	----	1916	10,835	301
1876	7,272	----	1917	11,000	154
1877	6,316	----	1918	10,700	56
1878	5,138	----	1919	7,400	7
1879	4,425	----	1920	3,809	
1880	3,209	----	1921		
1881	2,775	----	1922		
1882	1,953	----	1923	1,950	
1883	1,606	----	1924	4,665	
1884	1,025	----	1925	6,000	1
1885	1,144	----	1926	5,175	
1886	1,406	----	1927	4,359	1
1887	1,890	----	1928	3,700	17
1888	1,320	----	1929	3,565	5
1889	980	----	1930	4,940	131
1890	977	----	1931	4,000	158
1891	792	----	1932	481	106
1892	848	----	1933	377	329
1893	869	----	1934	595	142
1894	1,005	----	1935	562	168
1895	1,100	----	1936	435	248
1896	1,335	----	1937	1,525	209
1897	3,605	----	1938	3,945	187
1898	5,000	----	1939	3,624	222
1899	4,780	----	1940	5,479	439
1900	3,990	----	1941	5,665	207
1901	4,800	----	1942	7,971	213
1902	7,225	65	1943	13,785	67
1903	8,150	30	1944	12,201	4
1904	8,400	80			
1905	7,650	114	TOTALS	433,089	4,106

TOTAL PRODUCTION OF NEW IDRIA DISTRICT—437,195 FLASKS
valued at about $31,000,000

[1] Figures for 1838-1899 from Parker, E. W., U. S. Geol. Survey, 21st Ann. Rept., pt. 6, pp. 275-277 (1899). Figures for 1900-1944 from records of the State Mineralogist, Calif. Div. of Mines and of the Bureau of Mines, U. S. Dept. of the Interior.

[2] Includes production of San Carlos mine, reported to be about 60,000 flasks.

[3] A flask contained 76½ pounds previous to June, 1904, 75 pounds thence through 1927, and 76 pounds since January, 1928.

[4] No records available prior to 1900; production probably included in figures for New Idria mine. No production by other mines 1900-1944 for years not listed.

[5] No yearly figures available.

1860. In only two other periods (1889-1893 and 1932-1935) did it produce less than 1000 flasks per year. The cause of the first-mentioned drop is unknown but both of them doubtless reflect a lack of ore that could be worked at existing prices. As shown on figure 9, there was no parallelism between price and production until about 1910. Some of the greatest production, indeed, was made at very low prices. Since 1910, on the other hand, the production curve is almost exactly parallel to the price curve. More than anything else, these facts indicate a fundamental change in the grade of available ore. Until past the turn of the century most of the ore found was so high grade that it could be mined at a profit regardless of price. Since that time, however, the rate of discovery of large or high-grade ore bodies has slackened. Consequently until 1941 when several new ore shoots were discovered, it was necessary to mine lower-grade ore and to depend increasingly on treatment of dumps and stope fills of low-grade material rejected in earlier years.

Since the summer of 1941, when the first two of four new shoots were discovered in the eastern part of the mine, the grade of ore treated has risen markedly from that treated in the 20-year period preceding 1941. In 1942 and 1943 most of the virgin ore mined averaged 15-20 pounds of quicksilver per ton; nearly one percent quicksilver. An abundance of this relatively high-grade ore, coupled with very high wartime prices, resulted in a greatly increased production. In 1943, and again in 1944, production was greater than in any previous years in the mine's history.

GEOLOGY

The New Idria district is near the eastern edge of the Coast Range physiographic province and only a few miles from the border of the Great Valley of California. The geology of the region is described by several writers, including Anderson and Pack,[8] Mielenz,[9] and Phillips.[10] As shown on their maps and on the geologic map of California, the rocks between the San Andreas fault and the Great Valley are folded in a series of anticlines and synclines, which trend about N. 70° W., oblique to the San Andreas fault and other dominant structural features of the Coast Ranges. The New Idria district is on the northwestward extension of one of these folds, the Coalinga anticline.

The mapped area consists of a large oval body of strongly sheared serpentine, rimmed by Franciscan sandstone and by the upper Cretaceous Panoche formation and later sediments (see pl. 8). The structure is that of an asymmetric anticline dome marked on the northeast flank by overturned beds and by an irregular thrust fault—here termed the New Idria fault—along or near the Franciscan-Panoche contact. Except for the contacts along this thrust fault and the tear faults which offset it, the serpentine-Franciscan, and Franciscan-Panoche contacts around the remainder of the dome are, wherever they can be seen, marked by high-angle faults which encircle the core and generally dip away from its center. In all cases the fault-bounded serpentine and Franciscan rock

[8] Anderson, R., and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603, 220 pp., pls., 1915.

[9] Mielenz, R. C., The geology of the southwestern part of San Benito County, Calif.: Univ. California, unpublished thesis, 295 pp., maps, 1939.

[10] Phillips, R. M., The general geology of a part of the Priest Valley quadrangle, Calif.: Univ. California, unpublished thesis, 76 pp., maps, 1939.

core of the dome has been raised in relation to the enclosing Panoche sediments.

In the following paragraphs the rocks are described in chronologic order. Discussion of rock alteration is reserved for the section on ore deposits.

Rocks

Franciscan Group

The Franciscan group, of probable Jurassic age, is the oldest group of rocks in the mapped area (see pl. 8). Three quicksilver deposits have been found in it and it forms the hanging wall of the New Idria and several other deposits. The Franciscan group consists mainly of arkosic sandstone, with a little shale and conglomerate interlayered with basaltic lavas and associated lenses of chert. It is at least 5,000 feet thick. The most extensive exposures are along the southwestern part of the dome; elsewhere it appears as a discontinuous rim around the serpentine and also as small irregular inclusions in the serpentine.

In many places throughout the Coast Ranges the Franciscan rocks are overlain unconformably by Cretaceous and Tertiary sedimentary rocks and are intruded by serpentine and other igneous rocks. With few exceptions, all of the contacts in this district between the Franciscan rocks and the younger rocks are almost certainly faults. The only positive exception is the irregular body of Franciscan rocks near the northwest corner of the mapped area (pl. 8), which is in unconformable contact with Cretaceous and Tertiary rocks. Some of the inclusions of altered Franciscan rocks in the serpentine are possibly bounded by intrusive contacts, but the evidence is inconclusive.

The Franciscan sandstone, an arkosic rock, is medium- to coarse-grained and is made up of closely-knit angular fragments of feldspar, quartz, and mafic minerals, with rock fragments and flakes of shale. It is typically greenish gray but where silicified and pyritized it weathers to a buff or brown color. The rock is commonly much fractured and in some places evidence of bedding is indistinct or lacking, but elsewhere, as on Sampson and Idria Peaks, bedding planes in the massive sandstone are plainly seen.

Discontinuous, irregular bodies of altered basaltic lava and related volcanic rocks, here called greenstone, are interlayered in subordinate amounts with the Franciscan sandstone. They are largest and most numerous in the southwestern part of the district, but several examples are known in the vicinity of the New Idria mine. Most of them weather to form jagged, bold knobs and ridges which from a distance can readily be mistaken for outcrops of serpentine.

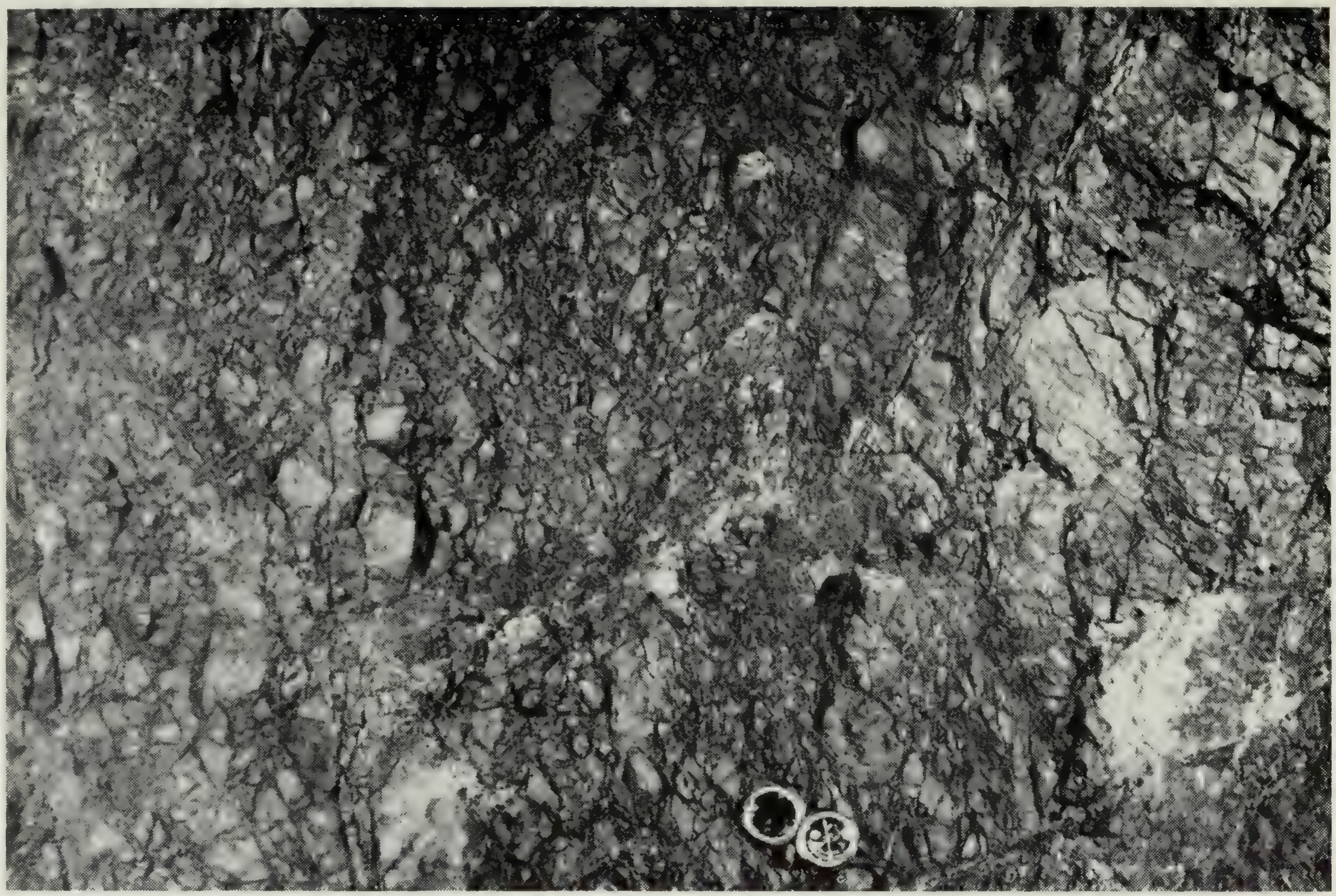
The rocks in the Franciscan vary widely in their resistance to erosion. Hence the formation weathers to somewhat more rugged and irregular forms than the other rocks in the area (see pl. 11).

In the absence of associated greenstone or chert it is not easy to distinguish the sandstone of the Franciscan group from that of the overlying Panoche formation. The Franciscan sandstone is in general more firmly cemented and more massive than that in the Panoche formation and it weathers to a characteristic soil that feels harsh or sugary underfoot. Veins of clear or white calcite, where they can be found, are diagnostic of the Franciscan sandstone. So too are veinlets of quartz, particularly if the quartz crystals are stubby and double terminated.

TYPICAL VIEW OF SILICA-CARBONATE ROCK OUTCROP
Silica-carbonate rock replaces serpentine along a fault zone that dips to right at low angle. Foreground is essentially unaltered serpentine. Picacho mine, looking southwest.

VIEW OF NEW IDRIA THRUST FAULT IN SAN CARLOS OPEN CUT

Looking northwest toward Idria Peak. Serpentine, here altered to silica-carbonate rock (sc) overlies indurated and pyritized Panoche shale and sandstone (ps). The fault plane actually dips away from the observer at a low angle. Characteristic topography and vegetation on serpentine (sp) and Franciscan (Jf) rocks shown in background.



VIEW OF TYPICAL LOW GRADE ORE-BEARING ROCK IN NEW IDRIA MINE

The Panoche shale is silicified and strongly fractured. Overturned beds dip 40° to right. Fractures that dip steeply to left contain cinnabar and pyrite; most other fractures are barren. Underground photograph on 4th level, looking N. 15° E. Brunton compass shows scale.

UNDERGROUND VIEW OF TYPICAL UNALTERED PANOCHE SHALE

The Panoche siltstone (gray) is soft and unaltered, with layers and lenses of sandstone (white). The beds are completely overturned (bottom sides up) and show several minor thrust faults. No. 10 adit of New Idria mine, about 3200 feet from portal and 150 feet from New Idria fault. Scale is 7 inches long.

Serpentine

Serpentine forms the entire central part of the district and also appears as relatively small slivers and fragments along the New Idria and other faults that separate the Franciscan rocks from the Panoche rocks (see pls. 8 and 9). Several minor quicksilver deposits are in silica-carbonate rock, a derivative of serpentine, and serpentine or silica-carbonate rocks form the hanging walls of several others.

Scattered outcrops throughout the serpentine area consist of hard, dark-green to brown serpentine which retains the textures of the ultramafic rocks from which it was derived. By far the greater part of the serpentine, however, is very strongly sheared and like soap or talc in feel and appearance. This incoherent kind, called ''caliche'' by the local miners, is commonly pale green but some of it is brown. Small pods and lenses of chromite, most of them cut by slickensided veinlets of emerald-green chrome garnet, uvarovite, are scattered throughout the serpentine. None of them are more than a few feet in length.

As shown on plate 8, the main serpentine body cannot be less than 2,000 feet thick and is probably much thicker.

As noted above, all the contacts between serpentine and the main bodies of Franciscan rocks are faults. Evidence as to the character of the contacts between serpentine and the small inclusions of metamorphosed Franciscan rocks is not so conclusive but some of them are certainly faulted and quite possibly all of them are. Detrital serpentine of the lower beds of the Upper Cretaceous rocks in this district shows that some of the serpentine, at least, is older than the Upper Cretaceous. The question of age is discussed briefly in the section on structural history.

Panoche Formation

The Panoche formation, of Upper Cretaceous age, consists predominantly of shaly beds and of sandstone. It entirely surrounds the body of serpentine and Franciscan rocks (see pl. 8) and extends beyond the mapped area to the southeast and northwest. It is of great economic importance, since it forms the country rock of the New Idria, San Carlos, and several other quicksilver deposits.

The Panoche is thinner in the New Idria district than away from it, where it is normally 20,000 or more feet thick.[11] In the southern part of the mapped area it is roughly 10,000 feet thick but farther north, particularly near the New Idria mine, it is less than 5,000 feet thick. Part of the thinning is doubtless due to original deposition, but part of it is as certainly due to the faulting out of lower beds around the edge of the New Idria dome. Unrecognized faults may possibly cut out other beds within the formation.

Except in one place, all the contacts between the Panoche rocks and the older rocks are faults. The exception is in the northwestern part of the mapped area in sec. 34 (pl. 8). Here basal layers of the Panoche formation, apparently unconformable on the serpentine and Franciscan sandstone, consist of conglomerate that contains serpentine, magnesite, and Franciscan debris. This conglomerate grades upward to shale and siltstone and is also underlain in places by shale of Panoche aspect.

[11] Anderson, R., and Pack, R. W., op. cit. pp. 39-45.

The Panoche formation consists of shale and concretionary sandstone in about equal proportions. Most of the sandstone is in the upper half of the formation, but lenses of similar sandstone, some of them several hundred feet or more in thickness, occur throughout the lower half as well. Sandstone and shale are shown separately on plate 9 but not on plate 8.

The shale is medium to dark gray and occurs in beds one to six inches thick. Some of these rocks are composed dominantly of clay-sized particles and are thinly layered, hence are true shales. The great majority, however, consist of silt-sized particles and are rather massively layered; they are therefore more accurately described as siltstone than as shale. The term ''shale'' is retained here for these fine-grained sediments because it is established in the literature and among most geologists who have studied the Panoche formation.

In thin section the shale was seen to consist of angular fragments of quartz and feldspar with varying amounts of undetermined finer-grained material. Grain size ranges greatly within short distances both along and across the lenticular beds. Thin layers and lenses of gray, arkosic, somewhat shaley sandstone are characteristic and give the rocks a striped appearance in fresh exposures (see pl. 13). Thin lenses and concretions of dense limestone are present but are not abundant.

The sandstones of the Panoche formation, which generally grade to shale both above and below, are light to medium gray when fresh but weather to buff or tawny yellow hues. They consist of sugary, fine- to medium-grained, massive to thinly layered arkosic sandstone. Quartz and considerable proportions of feldspar in angular to subrounded grains make up most of the rock, in which flakes of shale and dark mica, fragments of charred wood, and grains of serpentine are present locally. The mica flakes, which are characteristic of the Panoche sandstone, are seen under the microscope to be bleached biotite, light brown or honey colored, with a slight violet cast and a characteristic ''blistering'' along the basal cleavage. Thin and discontinuous beds of shale and conglomerate are present in places. Large spheroidal, ferruginous concretions are widely distributed but are of no help in distinguishing the formation because similar ones are present in several of the overlying Tertiary beds.

Except where it is indurated along parts of the New Idria fault, the shale in the Panoche formation is commonly soft and therefore tends to form deep, steepsided valleys. The sandstone, on the other hand, is resistant to erosion and hence forms high ridges and mountainous masses.

Younger Cretaceous and Tertiary Sedimentary Rocks

The Panoche formation is overlain conformably by the Moreno shale of Upper Cretaceous age and by several thousand feet of Tertiary beds that range from Eocene to Pliocene in age. None of them have any apparent bearing on the ore deposits of the district and except for the Moreno formation they are not shown separately on plate 8.

The Moreno crops out in a continuous belt near the north edge of the area shown on plate 8. It is 3,000 or more feet thick in the northwest corner but thins to about 1,000 feet at Idria and is even thinner farther northwest. The Moreno is characterized by chocolate-brown to maroon or purple platy organic shale which generally serves to distinguish it

from the Panoche formation and from the overlying Tertiary beds. The shale is made up of remains of diatoms and foraminifers in large part and contains concretions of limestone, a few of which contain cephalopods. It also contains several lenses of light-colored, arkosic, sugary sandstone, the larger of which are shown on plate 9.

The Tertiary beds are exposed along the north and south edges of the mapped area. They are described and mapped by Anderson and Pack, by Mielenz, .and by Phillips in the papers already cited and have also been rather exhaustively studied by the geologists of several oil companies. They consist predominantly of massive concretionary sandstone, siltstone and shale of various colors, and conglomerate. Many of the beds are fossiliferous. The Tertiary beds shown in the northwest corner of plate 8 are largely soft gray clay, probably deposited in a lake, and very similar to some of the Pliocene beds that are exposed in the central part of the Vallecitos syncline three or four miles to the northeast.

Syenite

Three small stock-like bodies of soda syenite, the largest of which is less than half a mile long, intrude the serpentine and the Panoche formations in the south-central part of the area shown on plate 8. They have no apparent bearing on the ore deposits. The rock is composed dominantly of albite, and is characterized by barkevikite.[12] The grain size varies widely, with crystals of barkevikite 6 inches or more long in some places.

Surficial Rocks

The surficial rocks in the district comprise landslides, slope wash, and alluvial valley fill. Only the landslides are shown on plates 8 and 9, but as mapped, these doubtless include slope wash in places. Some of the landslides are large, particularly those along the southern edge of the dome. In general, they are composed of the same material that forms bedrock at their heads; in the majority of cases this is the sheared serpentine of the core of the dome. Some of them are old and have relatively mature topography developed on their surfaces. Others have forced streams to cut new valleys around their edges and still others are present only as remnants along narrow ridge tops. Some of the more recent landslides are still active, moving slowly down hill each rainy season.

Structure

General Character

The New Idria district occupies an elongate asymmetric dome marked by overturned beds and an irregular thrust fault on its northeast flank and by steep faults along its other sides. This dome is a local bulge on the Coalinga anticline and, as is explained below, is probably closely related in origin to the serpentine intrusion that forms its core. The dome is flanked on its north and south sides by the Vallecitos and White Creek synclines, which parallel the main anticline.

Folds

Along the northeast side of the dome the Panoche beds are crumpled and overturned beneath the New Idria fault for distances of a few feet to 500 or more feet. Locally they are actually recumbent (see pl. 13).

[12] Troger, W. E., Spezielle petrographic der Erupivgesteine, p. 85, Berlin, 1935.

Away from the fault the beds gradually become vertical and then assume a normal dip to the northeast away from the dome. These relations are best seen in the No. 10 adit of the New Idria mine but are also very apparent on the surface. The angle of dip gradually decreases away from the fault but even in the Tertiary beds several miles from it there are local overturned folds. The Panoche rocks are also overturned along part of the northwest end of the dome, close to their fault contact with its core. Around the remainder of the dome the Panoche and younger rocks dip away from the center. In general the dips are very steep close to the core and decrease away from it.

Within a wedge-shaped graben at the northwestern end of the dome (secs. 34 and 35, T. 17 S., R. 11 E.) Panoche beds appear to lie with depositional contact on serpentine and Franciscan sandstone. Soft gray lacustrine (?) clay, probably of Pliocene age, lies across the eroded edges of all the older rocks within the graben. It is believed that the graben represents an upper segment of the Idria dome within which there has been little or no faulting along the contact between Panoche sediments and the serpentine and Franciscan rocks. The serpentine and Franciscan rocks of the remainder of the dome, on the other hand, are in fault contact with the Panoche sediments and represent much deeper portions of the core.

New Idria Thrust Fault and Later Tear Faults

The New Idria thrust fault extends along the northeast side of the dome and brings Franciscan sandstone and serpentine on the southwest, or hanging wall, side against the upturned and crumpled edges of the Panoche shale and sandstone beds on the footwall (see pls. 8 and 9). In places it is a complex fault zone, complicated by tear faults and other cross-cutting faults but elsewhere it is a simple thrust fault. Many of its features are shown on the various mine maps and diagrams and on plate 11. The thrust does not extend as a major structural feature past the ends of the serpentine and Franciscan rock core of the dome as most of the displacement has been taken up by the other genetically similar faults which mark the remainder of the core's perimeter. Since the thrust clearly resulted from oversteepening of the northeastern side of the anticline it is possible that locally the rocks along it are overturned rather than faulted. The displacement along parts of the fault must be considerable, however, and the presence at closely spaced intervals of gouge, of breccia, and of hydrothermally indurated zones is evidence that the fault is continuous as mapped.

Locally, particularly at some localities where the hanging wall is serpentine, the fault zone is little more than a foot wide. Elsewhere it is marked by 5 to 50 feet of gouge and in still other places by 100 to 300 feet of sheared and brecciated rock.

The irregularity of the fault is its most striking feature. Although the dip rolls from vertical to nearly horizontal within short distances, it is generally fairly steep toward the southwest. Of greater economic importance than the changes in dip are those in strike, for these are the principal controls of the ore deposits. Some of the abrupt changes from westerly to northerly trend are clearly due to north-northwest-trending tear faults. Possibly all of the abrupt changes in strike are actually due to tear faults, but this could not be proved in the field. Whatever their

origin, the effect of these changes in strike is a series of inverted troughs that dip toward the south or southwest. The fault surface thus has the general shape of a twisted and inclined sheet of corrugated iron.

Most of the tear faults dip rather steeply southwest but a few dip steeply northeast and others dip southwest at low angles. The movement on them was largely horizontal, the west walls having moved north; the vertical displacements are commonly small and are not uniform in direction.

Other Faults

Except in the small graben mentioned above, the exposed contacts between the serpentine and the main bodies of Franciscan rocks and between these and the Panoche beds are strongly sheared or brecciated. The New Idria thrust and the fault along the western boundary of the dome's core dip inward; all the other contacts dip away from the center of the dome. The boundary faults dip steeply whereas the internal sheared contacts between serpentine and Franciscan rocks are much less steep. In addition, the rocks along the contacts are indurated or otherwise altered at numerous widely separated places. These facts, together with the total lack of evidence of intrusive contacts or of contact-metamorphic effects (except possibly in some of the smaller Franciscan rock masses in the interior of the core), seem to the writers to be sufficient evidence that there was differential movement along the contacts, the core having moved upward with respect to the surrounding rocks. They are therefore classed as faults, though evidence is presented below that indicates the core's upward movement to have been due to intrusion rather than to faulting in the ordinary sense. According to the terminology adopted here, the contact which bounds the core rocks along the south and southeast side of the dome is a curved normal fault or a series of normal faults. The use of the term ''normal'' in describing faults thus carries ''no implications as to the type of stress which produced the fault, nor as to the movement of either wall relative to any outside datum.''[13]

Since the beds are in general parallel to the contacts, the displacement cannot be determined but it is not necessarily large.

In the New Idria mine, an east-northeast-trending fault, which dips steeply south offsets both the main New Idria thrust fault and the later tear faults. Though of major economic importance in the mine, its trace on the surface is marked by only a slight offset of the poorly exposed New Idria thrust fault. Similar post-tear-fault dislocations may exist elsewhere along the New Idria thrust but are recognized only at the Del Mexico mine, where a north-trending fault zone offsets the Idria thrust and an associated tear fault.

The Panoche and later beds in the outer parts of the dome are cut by numerous faults, most of which are of minor extent or importance and many of which are confined to the more brittle sandstone beds. Only one, the San Benito fault, is sufficiently important to show on plate 8 or to describe here. This fault splits from the boundary fault between Franciscan and Panoche rocks at a point near the New Tirado prospect and thence extends northwest through the Panoche rocks down the San

[13] Gill, James Edward, Fault nomenclature: Royal Society Canada Trans. ser. 3, vol. 35, sec. 4, pp. 71-85, (p. 78) 3 figs., May 1941.

Benito River valley. It is marked at intervals by zones of fracture and altered rock, and by local anomalous dips in the nearby beds. The displacement along it is not known. In the mapped part of its course it dips steeply to the west and is probably a normal fault.

Innumerable faults probably traverse the serpentine and account for much of its strongly sheared nature. Very few of these could be mapped with certainty, but the alignment of altered zones and of horses of Franciscan rocks suggests that the stronger fault zones are roughly parallel to the longer axis of the dome, though they converge a little toward its northwest end.

Structural History

Any interpretation of the structural history of the New Idria district must take account of certain remarkable facts. Among these are the asymmetry of the dome, the strongly sheared condition of the serpentine mass even at its core, the lack of intrusive contacts, and, excepting possibly the glaucophane schist in some inclusions and fault blocks, the lack of anything that can be regarded as evidence of contact metamorphism. Even more important is the fact that the core of the dome is encircled by faults, overthrust on the northeast and west and normal on the other sides.

These facts can best be explained by supposing that the serpentine when injected was cold or nearly so. Ultramafic rocks, already largely converted to serpentine, must have been exposed at the surface before the deposition of the lower beds of the Panoche formation, which contain serpentine, together with magnesitic material of a kind that is common in the serpentine. In order to explain the present relations between the serpentine and the Panoche and later rocks it seems necessary to assume that after the close of the Cretaceous and probably in mid-Tertiary time, the soft and essentially mushy serpentine was pushed upward as a plastic plug. The serpentine may in some places have reached the surface as a direct result of the upward thrusting. It carried with it numerous inclusions of Franciscan rocks and their metamorphic equivalents and even large masses of the Franciscan rocks by which it was overlain and surrounded. The emplacement of the serpentine can be likened to what happens when a concord grape is squeezed upward between the fingers. The soft pulp, containing seeds (inclusions), squirts from its tough skin in the direction in which confining pressure is least. The movement, at any given point, of the pulp relative to the skin might be classed as a normal or as a reverse fault, depending on whether the skin at that point faces upward or downward.

In the New Idria district, the shapes and inclination of the fault contacts, the evidence that there was more faulting at the northwest end of the dome than elsewhere, and the strong indications of tear faulting along the north side of the dome, all favor the idea that the serpentine rose from the south at a steep angle. The movement had a large horizontal component, with the west side moving relatively northward. The intrusion—perhaps ending in extrusion—of the serpentine may have been accomplished in several distinct stages; and that view is supported by the presence of abundant serpentine debris in nearby sediments of three widely different ages; in the Upper Cretaceous, the late middle Miocene, and the Pliocene.

Serpentine is abundant in the Upper Cretaceous Panoche formation where it is exposed in a graben at the northwest end of the dome.

A more widespread and conspicuous layer of serpentine debris is the well-known "Big Blue," of late middle Miocene age,[14] which is interbedded with more normal sediments along the western foothills of the San Joaquin Valley, opposite the Idria dome. The Big Blue consists almost entirely of serpentine flakes and boulders, and in the Big Blue Hills, about 8 miles east of the southeast end of the Idria serpentine body, it attains a maximum thickness of 1,000 feet. It thins northward and southward, but has been traced by Anderson and Pack[15] throughout an interval of about 20 miles. They recognized the unit as far south as the Coalinga oil field and later workers recognized it still farther south; Woodring[16] reported its presence in the uppermost zone of the Temblor sandstone in the subsurface section of the North Dome in the Kettleman Hills, and Bramlette[17] says that a few fragments of serpentine and uvarovite occur in the highest exposed bed of the Temblor sandstone at Big Tar Canyon in Reef Ridge, more than 30 miles southeast of the Idria dome.

As the thickest part of the Big Blue is nearest to the Idria serpentine body, which is the only large serpentine mass exposed nearby, this body in all probability is the source of the serpentine debris. The same conclusion has been reached by previous workers in the area. The enormous volume of the serpentine debris originally contained in the Big Blue—probably between 5 and 10 cubic miles—contrasted with the nearly complete absence of serpentine debris in the older Tertiary beds of the region, indicates that this debris came from a large serpentine mass that was uplifted and exposed rather suddenly. That is rendered all the more probable by the fact that the Big Blue includes serpentine boulders at least 40 feet in diameter, which now lie 8 miles from the Idria serpentine body.

Another upward movement of the serpentine, near the close of Pliocene, may possibly be recorded by the fine-grained serpentine debris that is locally abundant in beds of the Tulare formation, exposed along the western margin of the San Joaquin Valley about 15 miles northeast of the Idria dome. According to Anderson and Pack,[18] serpentine flakes are fairly abundant in certain loose crumbly beds that crop out south of Tumey Gulch. They do not say that serpentine occurs elsewhere in the Tulare formation, nor does Woodring[19] report the presence of serpentine in the Tulare formation at Kettleman Hills. This detrital serpentine may represent a period during which the core of the Idria dome was exposed and perhaps actively uplifted, though it is equally possible that the serpentine in the Tulare was derived from the Big Blue.

Assuming the serpentine to have come from the New Idria core, the last major uplift must have occurred before the widespread Pleistocene orogeny because the Tulare beds were involved in that orogeny. Uplifting may have continued, however, throughout the Pleistocene orogeny, at least intermittently, and very slight movement may possibly have occurred since that time. Such continuing or intermittent movement is suggested by the tear faults that offset the original thrust-fault plane; by evidence of renewed movement, later than the tear faults, along the New Idria thrust near the New Idria mine; by a fault in the New Idria mine that cuts all the above-mentioned faults; by still later fractures, now filled with cinnabar, in the altered rocks near the faults; and by post-mineral slickensided surfaces. The faults bounding the serpentine core may be largely a product of the last major period of movement (Pleistocene), although the first movement along them was certainly as early as Miocene, possibly even earlier than Cretaceous.

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[14] Woodring, W. P., Stewart, Ralph, and Richards, R. W., Geology of the Kettleman Hills oil field, California: U. S. Geol. Survey Prof. Paper 195, p. 144, 1940.

[15] Anderson, R., and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California: U. S. Geol. Survey Bull. 603, pl. 11 opp. p. 83, pp. 83-84, 1915.

[16] Woodring, et al., op. cit. pp. 135-136.

[17] Bramlette, M. N., Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Petroleum Geologists Bull., vol. 18, table 4 (p. 1564), p. 1572, fig. opposite p. 1567, 1934.

[18] Anderson, R., and Pack, R. W.. op. cit. p. 102.

[19] Woodring, et al., op. cit.

Even though the concept expressed here calls for a highly localized push from deep within the earth, it need not necessarily conflict with currently accepted theories as to the origin of Coast Range structures or as to the direction from which compressive forces were exerted. If a grape (serpentine) be placed between two boards (northwest-trending zones of lateral compression) the pulp will emerge from the open end of the skin almost regardless of the manner in which the confining boards are squeezed together.

QUICKSILVER DEPOSITS

Summary

The quicksilver deposits consist of cinnabar, with very little metacinnabar and native mercury, as veins and stockworks that occupy late fractures or fracture zones in altered rocks. The deposits of greatest economic importance lie in Panoche rocks beneath the New Idria thrust fault and include the New Idria and San Carlos as well as several promising but hitherto unproductive deposits. Several deposits of comparatively minor economic importance lie close to the faults around the south and west sides of the dome. Others occur in silica-carbonate rock along shear zones in the northwest part of the serpentine mass and a few are in altered sandstone of the Franciscan formation.

Ore shoots vary greatly in size. Those of the New Idria and San Carlos mines are measured in hundreds of feet but few others are more than 50 feet in greatest dimension. Grade of ore is also variable but most of that produced in recent years has been very low grade except for that from the new high-grade ore shoots in the New Idria mine. All known deposits are in places where abundant openings were formed during faulting. Abrupt changes in strike of the New Idria fault, due to tear faults or to bends, exerted the most important control on rock alteration and ore deposition but some ore bodies are definitely related to changes in angle of dip. Reserves of assured and probable ore are fairly large and in addition there is reason to hope that more ore will be found in several places.

Distribution

The New Idria and related mines, including the Sulphur Spring-Creek, Molino, and San Carlos, as well as the Wonder and several less promising mines and prospects are clustered along a three-mile segment of the New Idria fault in the northern part of the mapped area (see pls. 8 and 9). Other mines, including the Del Mexico, Archer, Florence Mac, New Tirado, and Breen, are scattered at rather widely spaced intervals along the New Idria fault and the normal faults that bound the south and west side of the dome. Still others, among them the Alpine, Aurora, and Picacho, are in the serpentine core. All of these last that bear any promise are grouped in the northwestern third of the serpentine mass.

Mineralogy

The mineralogy of the New Idria deposits is simple and like that of most other Coast Range quicksilver deposits. Cinnabar is the chief ore mineral in all mines; pyrite and, to a less extent, marcasite, are the only other sulphides that are at all abundant. Much of the cinnabar is in indurated and pyritized rock, unaccompanied by non-metallic gangue minerals. Some of the deposits along the edge of the dome are veins in

which cinnabar is associated with iron sulphides and with quartz or calcite. The gangue of the deposits in serpentine consists of silica-carbonate rock, which is made up of dense quartz, chalcedony, opal, and several kinds of carbonate minerals. Clay minerals are scarce but widespread in the ore bodies but are prominent constituents of fault gouge and of some altered sandstones.

Cinnabar (HgS). Cinnabar is the chief ore mineral throughout the district and is the only one in most of the mines. It ranges from a light, brilliant red to dark reddish purple in color, the intensity of shade depending directly on the size of the individual particles or crystals. Most of that in the New Idria and geologically similar deposits occurs as grains, films, and crystalline aggregates or veinlets that fill interstices of indurated and fractured rocks (see pl. 12). Gangue minerals are absent or at best very rare. In parts of the New Idria mine, notably along the "Elvan Streak" described below, and in the San Carlos, Del Mexico, and Archer mines, much of the cinnabar forms distinct but irregular veins, with or without gangue minerals. Some of the cinnabar veins that incompletely fill open fractures in the New Idria and the San Carlos mines are locally studded with globular masses of cinnabar as much as an inch across. These commonly show colloform banding in cross section, and are called "strawberries" by the miners. In most of the deposits in serpentine the cinnabar is intimately intergrown with dense quartz and forms highly irregular veins and lenses in silica-carbonate rock.

Cinnabar was the last mineral to form in most places though locally it was followed by pyrite and marcasite. In very few places is there any evidence of post-mineral movement; but in the Archer mine, and to a less extent in the New Idria, some of the cinnabar is polished and slickensided.

The light-red, pulverulent variety of cinnabar, called "paint" is widespread but seldom abundant. It is commonly later then the more massive varieties and may possibly be of secondary origin. Grains and flakes of cinnabar are associated with crusts of secondary hydrous sulphates of iron and magnesium in many parts of the New Idria mine but they are believed to have been flaked off the walls and lifted up by the growing sulphate crystals rather than to be of secondary origin.

Native Mercury. Native mercury (quicksilver) has been found in fair quantity in ore from the Picacho, Alpine, and Andy Johnson mines, and small quantities are reported to have been seen in the New Idria and a few others. It is not of great commercial importance anywhere.

Metacinnabar (HgS). Small quantities of metacinnabar, the black mercuric sulphide, are occasionally found in ore from the recently discovered ore shoots in the eastern part of the New Idria mine and from the Aurora mine. According to Becker the New Hope vein in the New Idria mine yielded "some tons of metacinnabar."[20] At New Idria, metacinnabar was noted only at two or three localities, although the ore shoots were examined and mapped during many stages of their development. In the few specimens seen, the metacinnabar formed massive layers, as much as an eighth of an inch wide, but never more than a few inches in extent, along the edges of wider fracture zones, incompletely

[20] Becker, G. F., Quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mono. 13, p. 302, 1885.

filled with crystalline cinnabar, apparently younger than the metacinnabar. At the Archer mine the ore contains appreciable quantities of the mineral, veined and partly replaced by cinnabar, pyrite, and marcasite. Even here it is less abundant than cinnabar.

Rock Alteration

Since all the ore deposits are enclosed by hydrothermally altered rock, recognition of the different kinds of alteration and of their significance is necessary to an understanding of the ore deposits themselves. Partly because they all give clues to the distribution of fault zones, five kinds of altered rocks are shown in the accompanying maps. These include two kinds of alteration of sedimentary rocks, (1) argillized and slightly indurated sediments, and (2) more strongly indurated and pyritized sediments; and three kinds of altered serpentine (1) slightly silicified serpentine, (2) silica-carbonate rock, and (3) magnesitic silica-carbonate rock. Only the altered sedimentary rocks and the ordinary silica-carbonate rock require description here, as these are the only ones known to contain workable ore bodies. In addition to the forms of alteration mentioned above, some of the arkosic sandstones in the Franciscan and Panoche formations have been partly altered to clay minerals.

The Panoche beds have been indurated in varying degree. At intervals along the circumference of the dome, both beneath the New Idria thrust fault and the steep reverse fault on the west, and above the normal faults on the south, pyrite is widely but rather sparingly disseminated through the brittle, relatively hard, indurated rocks, in the form of veins and veinlets. Shale is ordinarily more strongly indurated than sandstone, which is more apt to be partly converted to clay, but both Franciscan and Panoche sandstones are indurated locally, particularly near the New Idria mine (pl. 9).

In the deeper part of the New Idria mine, below No. 8 level, sandstone is commonly indurated and metallized, whereas in many localities shale is unaltered and unmetallized or nearly so. This may possibly be explained as a result of higher pressures on the rocks at this greater depth. The shales, though relatively permeable where cut by many open fractures near the surface, would be much less permeable at greater depth. The sandstones, however, would retain open fractures at a greater depth than the less competent shales.

As explained further in the section on structural control of the ore deposits, all the altered zones are in places where the rocks are strongly fractured due to changes in dip or strike of the faults. Each altered zone is bounded on one side by the controlling fault; on the other side it is bounded by minor faults or else grades to unaltered rock.

In this report the term "indurated" is used to describe sediments rendered hard and brittle by an unknown process of hydrothermal alteration which was believed, during the earlier part of the work, to consist essentially of an introduction of silica. Later studies, however, have shown that most of the induration of the Panoche sediments is not the result of silicification, although some silicification has occurred locally, as at some of the outcrops on San Carlos Peak. Here the shale is extremely hard and flinty, being too hard to scratch with knife steel and breaking with a hackly to sub-conchoidal fracture. This silicified rock shows a grayish-white mottled bleaching that distinguishes it from the gray to black color of most of the indurated shales of the district.

Many narrow quartz veinlets fill closely spaced intersecting fractures in this dense, brittle rock. Hard, siliceous cinnabar veinlets incompletely fill late fractures at one point—the only cinnabar observed in this dense flinty silicified rock. Most of the indurated shale in the New Idria mine area and much of it in the Molino and San Carlos mine areas, is by no means as hard as the San Carlos Peak outcrops; it can be scratched with a knife and its overall hardness commonly ranges from 4-5 in Moh's hardness scale. Pyrite and probably minor amounts of marcasite are common in these rocks as distinct crystals on fracture surfaces, as fracture fillings, and as disseminated crystals or inter-grain cement. Iron sulphide is commonly present in amounts up to a few percent but locally may make up 10 percent or more of the rock. Cinnabar is present locally as veinlets and breccia cement, and although it is accompanied in places by small amounts of quartz and kaolinite, the cinnabar is not silicious. Specimens of indurated shale that are too hard to be scratched with a knife commonly contain much pyrite as an inter-grain cement, which probably accounts for the unusual hardness. No bleaching or light-colored mottling similar to that seen in the silicified rock was observed in these gray to black indurated rocks. Study of thin sections revealed no definite evidence of silicification, although very small discontinuous veinlets of chalcedonic quartz are common. Neither is there definite evidence of introduced silica to be found in thin sections of indurated sandstones, although there appears to be some recrystallization along brecciated boundaries of both quartz and feldspar grains. No recognizable carbonate was observed.

In an effort to determine the nature of the alteration, specimens of unaltered shale and sandstone were submitted to the chemical laboratory of the Geological Survey for analysis. It was only possible to run two sets of incomplete analyses, whose results appear below. As the two analyses in each set do not represent samples from the same bed the results are not conclusive; each sample, however, represents 5-10 chips taken at intervals of a foot or more along a working and should therefore represent the average composition of several beds.

It can be seen from this table that the alteration was not a simple addition of silica at the expense of the other constituents. The altered sediments have not only increased silica contents, but have also among other changes notable increases in the total alkalies.

Silica-carbonate rock ("quicksilver rock") is more widespread than the other kinds of altered serpentine shown on plate 8 and is like that commonly associated with quicksilver deposits in serpentine throughout the Coast Ranges. It consists mainly of chalcedony, quartz, opal, and granular carbonate, most of it near ankerite in composition. Weathered silica-carbonate rock forms prominent and distinctive outcrops (see pl. 10) which are buff to brown in color and have a porous texture due to solution and removal of carbonate and disseminated pyrite. There are several reasons for believing that the bodies of silica-carbonate rock were formed as discontinuous lenses along fault zones, some of which have very low dips, but few such faults are traceable through the serpentine, and therefore are not shown on plate 8.

The arkosic sandstones of the Franciscan formation that form the hanging wall of the New Idria ore body have been partly altered to clay minerals. The principal effect of this alteration has been to render the sandstone softer and less brittle than the indurated Panoche shales on the footwall side of the fault. In some places sandstone layers in the contorted Panoche formation have been similarly altered.

Chemical analyses of unaltered and hydrothermally altered sandstone from the New Idria quicksilver mine, San Benito County, California [a]

	Shale [b]		Sandstone [c]	
	Unaltered 1	Altered 1a	Unaltered 4	Altered 4a
Fe (water soluble)	0.52	0.38	0.17	0.52
Fe (soluble in 1-1 HNO_3 after water leach)	2.53	3.28	1.50	1.90
CO_2	2.14	.12	1.	.4
SiO_2	65.67	70.43	76.61	77.82
Al_2O_3	17.16	14.92	12.01	11.81
Fe_2O_3	2.21	.70	.39	.45
FeO	----[d]	----[d]	1.30	.36
TiO_2	.81	.60	----	----
CaO	.07	.10	none	none
MgO	1.26	.43	.60	.07
Na_2O	.92	2.02	2.39	3.58
K_2O	4.16	7.56	2.61	3.34
Total	97.45	100.54	98.58	100.25
Total Fe	5.26	4.36	3.36	3.23

[a] Shale analyses by W. W. Brannock. Sandstone analyses by E. Claffy: U. S. Geological Survey.

[b] Unaltered sample taken on #5 level 20 feet east of "1st 5 east" ore shoot, in north-trending cross cut. Altered sample from "1st 5 east" ore shoot, on #5 level, and approximately on strike of unaltered sample (see pl. 18).

[c] Unaltered sample taken in 3 compartment cribbed raise (see pl. 18) between #7½ and #8 levels. Altered sample taken in same raise from a point half way between #8 level and #9 level, down to #10 level. Also for a distance of 80 feet westward along #9 level drift.

[d] Total iron.

Form and Character

All the quicksilver deposits occupy late fractures or fracture zones in bodies of indurated and pyritized rock or of silica-carbonate rock. On the basis of their geologic setting, the deposits can be divided into three classes: those along the New Idria thrust fault, those along normal faults in the southwest part of the district, and those in silica-carbonate rock in serpentine. Members of the last two classes have proved far less productive than the first.

All but three of the deposits of the first-mentioned class are on the footwall side of the New Idria fault. One of these exceptions was the rich New Hope vein, described briefly in the paragraphs on the New Idria mine; the other exceptions are the Wonder mine, a pipe-like ore body in crushed Franciscan sandstone between the New Idria fault and a strong tear fault (see plate 9), and a relatively insignificant prospect about 2,000 feet east of the Wonder, where cinnabar coats fractures in a lens of chert in the Franciscan formation.

The other deposits on the footwall side of the New Idria thrust are typified by that of the New Idria mine, which is described in some detail below. They consist of cinnabar-bearing veins and stockworks in indurated and pyritized shale and sandstone of the Panoche formation. Most of the fractures, whether or not they are now filled with cinnabar, were formed by renewed movements on the New Idria fault after the rocks had been indurated and they are therefore closely related to the major fault both in origin and in space. The richer parts of most deposits are distinctly veinlike and follow strong fracture zones but the deposits as a whole are irregularly lenticular or pipelike in form.

Some of the deposits, notably those in the lower parts of the New Idria mine, consist of disseminated cinnabar in slightly indurated and kaolinized sandstone. These are generally less rich and less extensive than are the ore bodies in indurated shale, although there are notable exceptions, such as the rich, pipelike Fine Weather ore shoot which is in indurated and pyritized arkosic sandstone in the New Idria mine. At the Del Mexico mine and also at the Anita mine, all the ore is in sandstone (figs. 6, 7) but at both deposits the shale is unaltered, hence less brittle, than the sandstone.

Among the deposits in indurated rocks along normal faults, the Archer (pl. 14) and the Florence Mac (fig. 5) are the only ones of any importance. In both of these, and probably in others, cinnabar occurs in a series of steeply inclined, fairly narrow veins that cut indurated shale on the hanging-wall side of the normal fault that separates serpentine and Franciscan rocks from the Panoche beds. The veins are inclined to the major fault at variable but generally large angles.

The deposits in silica-carbonate rock are, like their enclosing rocks, highly irregular in form. They consist in general of series of lenses, veins, and veinlets of siliceous cinnabar. These have no definite orientation but in a very general way are transverse to the elongation of the enclosing silica-carbonate bodies.

Size and Grade of Ore Shoots

Those parts of the ore deposits that contain workable ore, called ore shoots, vary greatly both in size and grade. The largest and richest one in the New Idria mine was 800 feet high, 300 feet long, and 25 to 150 feet wide. A second one in the New Idria and the main San Carlos deposit were comparable to the first in dimensions but both of them were elongate horizontally rather than vertically. The San Carlos ore shoot was, indeed, a nearly horizontal tabular body. Other ore shoots in the New Idria and other mines of the district are variable in size but few are much more than 50 feet in greatest dimension and most are narrow.

Few valid generalizations can be made regarding the grade of ore. Most of that produced in the first half of the New Idria mine's history was very rich and some of it contained 10 percent (200 pounds to the ton) or more of quicksilver. Incomplete records in the company files give some information as to grade. They show, for instance, that the average recovery for a 12-month period, March 1903 through February 1904, amounted to 12.24 pounds of quicksilver per ton of furnace ore. During this period a daily average of nearly 150 tons of ore was treated by the two Scott furnaces. The average tenor of the ore may have been considerably higher than this recovery due to loss in the Scott furnaces. Again, in December 1916 the average furnace heads were 11.4 pounds of quicksilver per ton, according to assay records. Recovery, however, averaged only 59.8 percent of this figure, or 6.81 pounds per ton. A large portion of this very high apparent loss was probably due to poor sampling technique or to faulty assay practice. The grade of ore mined has diminished greatly in recent years and most of the newly mined ore sent to the New Idria furnace previous to 1941 probably contained considerably less than 10 pounds of quicksilver to the ton. Ore produced by the smaller mines has probably ranged from 5 to 25 pounds to the ton. It is safe to say that only under very exceptional conditions can ore that contains as little as 5 pounds to the ton be mined profitably from

underground. The New Idria mine's success in treating lower-grade material (between 3 and 4 pounds to the ton average) was due to the fact that most of the ore was in surface dumps which could be handled cheaply by large-scale operations.

Ore produced by the New Idria mine since the discovery of new ore shoots in 1941 contained 15 to 20 pounds of quicksilver per ton. This average is made up in large part of ore of about this grade mixed with relatively small amounts of high-grade ore (80-160 pounds of quicksilver per ton) and low-grade ore containing as little as one pound per ton.

Origin and Structural Control

The origin of the quicksilver deposits is closely linked with that of the zones of alteration, for cinnabar was deposited in those rocks that were most brittle and hence most capable of retaining open fractures. Naturally the most brittle rocks accessible to the rising ore solutions were those which had previously been indurated or altered to silica-carbonate rock.

After the faults had been formed, hydrothermal solutions from considerable depth rose along some of them. In favorable places they indurated shale and some sandstone, veined and impregnated the rocks with pyrite, and transformed serpentine to silica-carbonate rock. The arkosic sandstones, particularly those in the Franciscan formation, were partly altered to clay minerals. At some time after the altered zones had been formed, probably very soon thereafter, slight renewed movements along the faults fractured the now brittle indurated rocks and the silica-carbonate bodies. Hot solutions again rose, or continued to rise, along the faults and deposited cinnabar and its associated minerals in the newly formed fractures. The resultant ore deposits have not been greatly affected by slight post-mineral fault movements nor by weathering agencies.

Both processes—rock alteration and cinnabar mineralization—were controlled by the same structural features. That is, both kinds of solutions followed the faults until they reached open places where pressures were released and where they could spread out to flow more slowly and to cool sufficiently to deposit their contents.

The concentration of hydrothermal activity in the northwest part of the dome is probably partly due to the fact that the rocks at this end were more strongly broken and faulted, hence more open, than elsewhere.

The concentration of faulting in this area seems to be due to a local weakness in the serpentine of the Idria dome manifested very early in the history of the dome. The evidence for this is the pronounced thinning of the Upper Cretaceous formations in the vicinity of the New Idria mine. As previously stated part of this thinning is the result of thrusting but part of it is due to original deposition. Taliaferro [21] states:

> "This part of the Coalinga anticline was uplifted prior to the deposition of the Pacheco (pre-Panoche Upper Cretaceous) and probably stood out as a low island during that time and the beginning of the deposition of the Asuncion (Panoche-Moreno group) ; it was finally submerged and covered with sediments during Asuncion time."

It seems reasonable to infer that this early uplift was localized by a weakness in the serpentine core.

[21] Taliaferro, N. L., op. cit. p. 133.

The New Idria thrust fault was the locus of much of the rock alteration, possibly because it was more continuous both laterally and vertically than the other faults. The tear faults that offset the thrust were clearly the most important structural controls. The ore solutions followed up along the inverted troughs formed by the bending of fault strikes from west-northwest to north-northwest. The heavy gouge zones, like diversion dams, guided the solutions in their rise; but they were not entirely impervious dams, for altered zones, some of them ore-bearing, occur on both sides of the New Idria fault. All the strongly altered zones in the hanging wall of the thrust at the New Idria mine, however, are localized along tear faults which intersect the main hanging-wall thrust.

The intersections of the tear faults and the New Idria thrust fault zone were the places where the rocks were most thoroughly crushed. The contorted and broken shale beneath the inclined inverted troughs was more permeable and hence more readily indurated than adjacent Panoche rocks. Locally where solutions did work up into the hanging wall, development of clay minerals in the Franciscan sandstones soon rendered them soft and yielding rather than hard and brittle so that further flow of solutions was impeded or retarded. This difference in degree and kind of alteration between different rock types partly accounts for the presence of nearly all the deposits in Cretaceous sediments rather than in Franciscan sandstone or serpentine.

Abrupt changes in dip were second only to bend in strike in controlling rock alteration and ore deposition. The New Idria fault is no exception to the well known rule that the low-dipping segments of thrust faults are more open and therefore more favorable to ore deposits than are steeply dipping ones. The rich San Carlos ore shoot, as well as several of those in the New Idria mine, lie beneath the fault in places where it dips at relatively low angles.

The upper parts of the four newly discovered ore shoots in the New Idria mine are actually controlled by the intersection of footwall and hanging-wall faults, but both ore and indurated rock stop 10 to 15 feet short of the actual intersection, grading upward to contorted and slightly altered shale. The two faults are parallel in strike but diverge downward in dip so that the intersection is a nearly horizontal line; possibly the difference between this and other inverted troughs is that here the horizontal ''ridge pole'' caused stagnation of rising solutions and prevented strong alteration or metallization of the rocks directly beneath it. There is some indication that the topmost high-grade ore shoots in the old part of the mine were controlled by similar features, in which case they probably never extended more than 100 feet higher than the outcrop as it existed at the time of discovery.

With one exception, the reasons for the localization of the altered zones along the normal faults around the south side of the district and within the serpentine core are not clear. The exception is the Aurora deposit, where the silica-carbonate rock was localized by an abrupt change in dip of the controlling fault plane. Doubtless more complete exposures, either natural or artificial, would reveal significant changes in strike or dip of the controlling faults at other places.

Reserves

The district's proved reserves in April 1945 consisted of the unmined portions of three of the four ore shoots discovered since 1941 at the eastern

part of the New Idria mine, which were estimated by the management to contain 20,000 flasks of available quicksilver. Probable reserves of partly developed ore consisted of the comparatively low-grade ore and stope fill left by former operators between the 5 and 10 levels of the New Idria mine. These reserves probably contain not much more than 8,000-10,000 flasks of quicksilver. Assured and probable reserves seem therefore to be in the neighborhood of 30,000 flasks.

The outlook for finding entirely new ore bodies is rather bright. It seems safe to say that the smaller deposits throughout the district may eventually yield several thousand flasks of quicksilver. It also seems entirely within the bounds of possibility that new ore will yet be uncovered in the New Idria mine itself, or in the downward extension of the adjacent Sulphur Springs-Creek body, already proven by recent development work to exist as deep as the 10th level of the New Idria mine. It seems doubtful that any new ore shoots will be found in either of these areas of the size and richness of the recently discovered shoots in the eastern part of the main mine. Also promising are the indurated zones in portions of the Molino adit. These all contained a few veinlets of cinnabar, and none of them cropped out. If the apex of these indurated bodies is fault controlled as all of the mapped ones have been, it is probable that at least one commercial shoot will be found somewhere above the Molino adit level.

In time of national emergency the *rate* at which quicksilver can be produced is more significant than the total potential reserves. The possible rate of production depends on many factors, among them character and grade of ore deposits, development necessary to open new ore shoots, existing reduction plant capacity, and the price of quicksilver.

Judging by their production record during the past 40 years, the smaller mines in the district reasonably can be expected to produce from 100 to 200 flasks annually, almost regardless of price. Assuming conditions similar to those of 1945, with able and efficient management, a plant capacity of 400 tons per day, a price of at least $100 per flask and costs commensurate with those of 1945, the New Idria mines together can probably produce about 10,000 flasks a year for 2 to 3 years and possibly longer.

Since continued production, even from the assured reserves, is dependent on a minimum price of about $100 per flask, it is clear that new ore must be sought and developed while prices are high enough to insure continued operation. The development program of the New Idria mine for the past 6 years has been and continues to be aggressive and intelligent. The present condition of the mine workings is such that a vigorous development program could be continued more efficiently and more rapidly than at any time within the last 25 years.

Suggestions for Prospecting

The foregoing paragraph should make fairly apparent that search for new ore deposits should be logically confined to places where the sedimentary rocks have been indurated or where serpentine has been converted to silica-carbonate rock. All but the smallest of such altered zones that crop out at the surface are shown on the accompanying maps. The most promising ones are those along the New Idria thrust fault, whose possibilities are discussed below under descriptions of the mines.

Some of the altered zones are doubtless nearly or quite barren of workable ore deposits. Lack of commercial ore in the outcrop does not necessarily imply, however, that a given altered zone is not worthy of prospecting. This is particularly true where there is reason to believe that an outcrop of altered sandstone is underlain by indurated shale, which is generally more favorable for ore than is sandstone.

No generally applicable rules for seeking ore shoots within known mineralized ground can be given. This is because ore shoots are commonly controlled by minor structural features that are seldom apparent in advance of development. Nevertheless, careful consideration of all the structural evidence, especially of the relation of the ores to the major faults, should result in relatively efficient and economical development.

MINES

The following table summarizes the available non-geologic facts for all the mines and nearly all the prospects in the district. Since it is impossible to present here complete geologic descriptions of all these mines, only a few of the more typical or important ones are described separately in the following paragraphs. Several others are mentioned briefly and their differences from the typical examples are pointed out.

In a district as old as New Idria, it is not surprising that many mines and prospects have changed names several times. The following list shows all the old names that have come to the writers' attention. Correlations with present-day names are based on the best available information.

Old name	*Present name*
Boston	Clear Creek
Chiquita	Anita
Cody	Breen
Don Juan	Breen
Don Miguel	Breen
Esmeralda	Alpine
Hernandez	Picacho
Los Picachos	Picacho
Mexican	Del Mexico
Monterey	Clear Creek
Morning Star	Aurora
Nieson Group	Breen
Ramirez	Picacho
Rita	Anita
San Benito	Breen

Archer

The principal workings of the Archer mine consist of fairly extensive open cuts, abandoned for some years, and a single adit (see pl. 14). The deposit is in altered Panoche shale just above a fault contact with serpentine. This fault, which trends north of east and dips 65°-70° S., is everywhere marked by 5 to 20 feet of strongly sheared serpentine and locally by a few comparatively small lenses of silica-carbonate rocks. The southward-dipping Panoche shale beds are moderately fractured and rather strongly indurated for distances of 40 to 100 feet from the fault. They contain disseminated iron sulphide minerals and a little cinnabar.

A series of rather well-defined shear zones that strike N. 30° W. to N. 20° E. and dip at various angles cut the indurated shales. They do not cross the main fault nor can they be traced southward into unaltered

Records of mines in New Idria district, California

Mines	Location (Mount Diablo meridian)			Owner in 1941	Address[1]	Approximate altitude (feet)
	T.S.	R. E.	Sec.			
Alpine	18	11	13	H. B. Leonard	Hollister	3,600
Anita	18	13	17	Box 57, Anita Mining Co.	Idria	----------
Archer	19	13	3	H. B. Byles	Coalinga	3,500
Aurora	18	12	5	North American Mining Co.	Boston, Mass.	4,000
Breen Group	18 18	12 11	31 36	Breen Estate	Hernandez	2,750
Del Mexico	18	13	22, 27	Lyle Caustie	Mendota	3,700
Flint Group Andy Johnson Clear Creek Fourth of July Red Rock	 18 18 18 18	 12 12 12 11	 18 2,11,12 18 11	 W. C. Webster	 Hernandez	 4,400 3,000-3,700 4,250 3,300
Florence Mac	18	12	32	L. H. Burns and Arthur Hoag	King City, Hollister	3,000
New Idria Molina New Idria Ranchito San Carlos Sulphur Spring Creek	 17 17 17 18 17	 12 12 12 12 12	 33 32 33 4 32	 New Idria Quicksilver Mining Co.	 San Francisco and Idria	 3,850 2,300-3,600 3,000 4,750 3,300
New Tirado	18	12	31	S. Tirado	Hernandez	3,600
Picacho	18	12	19, 20	Hernandez Quicksilver Mining Co.	Hernandez	4,300
Tirado	18 18	12 11	18 13	Ben & Paul Hilden	Hernandez	4,250
Tirado & Shear	18	11	12	S. Tirado & William Shear	Hernandez	3,300
Wonder	17	12	31	Paul Gonzales	King City	4,000

[1] All addresses in California except as noted.
[2] I, deposits in indurated shale and sandstone of Panoche formation beneath New Idria thrust fault; II, deposits in indurated shale of Panoche formation above normal faults; III, deposits in silica-carbonate rock along shear zones in serpentine.

Records of mines in New Idria district, California—Continued

Mines	Workings approximate length (feet)	Workings accessible 1941 (feet)	Discovery date	Last year of recorded production	Reduction method	Class of deposit[2]
Alpine	100 ft. plus shallow open cuts[5]	100 plus shallow open cuts[5]	1941	1943	Retort	I
Anita	1,500	200	1910	1939	20-ton Scott, retort	III
Archer	750 plus open cuts	500 plus open cuts	1904	1942	Retort	II
Aurora	1,600	1,500	1853	1943	15-ton rotary	III
Breen Group	300	50	?	1933	----	II
Del Mexico	800 plus open cuts	500 plus open cuts	1860	1941	Retort	I
Flint Group Andy Johnson Clear Creek Fourth of July Red Rock	1,500 plus open cuts	300 plus open cuts	pre-1880	1942	Retort	III
Florence Mac	900	600	1904	1939	Retort	II
New Idria						
Molino	7,500	1,500	pre-1880	1941	Four 100-ton rotaries	
New Idria	20 miles	10 miles	1853	1944		I
Ranchito	100	----	?	1918		[3]
San Carlos	8,500	1,000	pre-1860	1931		I
Sulphur Spring Creek	2,500	750	?	1941		I
New Tirado	100	100	1938?	----	Retort	II
Picacho	1000 plus open cuts	200 plus open cuts	pre-1871	1940	Retort	III
Tirado	Open cuts	Open cuts	1914	1942	----	III
Tirado & Shear	Open cuts	Open cuts	1925	----	----	III
Wonder	400	325	1908	1942	Retort	[4]

[3] Ore in indurated Panoche sandstone half a mile north of New Idria thrust fault. Inaccessible workings are possibly in bedrock beneath landslide.
[4] Ore in crushed sandstone of Franciscan formation between New Idria thrust fault and a strong tear fault.
[5] Data as of February, 1943.

shale. They range from 1 to 15 feet in width and consist of strongly fractured indurated shale with irregular veins and lenses of marcasite, pyrite, and quartz with considerable amounts of cinnabar and metacinnabar. In some places the entire width of the shear zone is ore but elsewhere the ore-bearing zones are narrow. So far as can be determined, the veins tend to be both wider and richer near their intersection with the main fault than elsewhere.

Several vein zones have been stoped for vertical distances of 35 to 40 feet and two winzes on one vein have demonstrated that good ore extends to 100 feet below the adit level. These facts, together with the evidence offered by the open cuts, show that ore is essentially continuous for at least 200 feet vertically.

It is clear that the ore is closely related to the fault and that future prospecting must be confined to shear zones in indurated shales near the fault. It is improbable that any very large deposit exists in this vicinity but maintenance of a small, comparatively regular, production should be entirely possible for a number of years.

Aurora

The Aurora mine is the oldest and the most thoroughly explored mine in silica-carbonate rock. About three-fourths of its total recorded production was taken out between 1933 and 1940, but it is doubtful that the operations showed an overall profit even during this period. The mine was temporarily abandoned in the spring of 1941, but has been worked for short periods since that time.

In addition to the extensive underground workings shown on plate 15, a series of broad shovel-cut benches have explored nearly the entire surface of the hill on which the mine rests. Their principal effect was to show that most of the silica-carbonate rock "outcrops" were actually slide blocks of varying size that had broken off the main outcrops.

The main Aurora deposit lies along a fault that strikes about N. 45° W. and dips southwest. Though it cannot be traced through the unaltered serpentine, it seems to be an extension of the strong tear fault on which the Wonder mine is situated and it probably extends southeastward through the upper San Carlos Creek valley (see pl. 9).

The mineralized zone parallels the fault and is about 400 feet long and 100 feet wide. In this zone the soft serpentine contains several large irregular bodies of silica-carbonate rock, most of them very siliceous. The silica-carbonate rock grades into unaltered serpentine locally but in most places the contacts are well-defined planes of shear. Most of the shears in the serpentine are nearly horizontal as are linear elements and late fractures in the silica-carbonate rock. This fact, coupled with evidence as to the general shape of the mineralized zone, indicates that the controlling fault dips westward at very low angles near the surface but steepens in depth, much as the New Idria fault does at the San Carlos mine (see section B-B, pl. 9).

Cinnabar, with a little metacinnabar and much quartz and chalcedony, forms irregular veins and "bunches" along late fractures in the silica-carbonate rock. Where those veins are closely spaced they result in workable ore bodies. As can be seen on plate 15, the stopes that have been worked are irregular in form and most of them are only a few feet in greatest dimension. They follow no recognizable pattern, either individually or as a group.

Little hope can be held for finding additional ore above the 401 tunnel level but more ore may yet be discovered by following the mineralized zone downward along the controlling fault. If, however, the fault dips more steeply in depth than it does near the surface, as is suspected, it is unlikely that the ore bodies will be as large as those already worked.

Most of the work since 1941 was done in a small siliceous silica-carbonate lens a quarter of a mile south of the Aurora glory hole. This lens, not more than 100 feet long and 45 feet wide in outcrop, trends about N. 60° E. and grades to soft sheared serpentine. On the south side the contact is estimated to dip from 15° to 45° S. This body is exploited near its eastern end by an open cut 40 feet long, 20 feet wide, and as much as 35 feet high. The cut trends S. 16° W. and transects fractures that trend N. 50° E.; it dips 55-60° NW. The silica-carbonate rock in the walls contains cinnabar throughout, but most of it probably contains less than one pound of mercury per ton. A stope 22 feet in diameter and about 12 feet high has been opened in the face of the cut. Much of the recent production came from this stope but a grab sample from the northeast wall assayed 2.5 pounds of mercury per ton and even lower grade rock is exposed in the other walls. A 35-foot drift from the southwest corner of the cut follows a southwestward-trending fracture but it exposes soft sheared serpentine in its face and does not cut any ore.

A shaft in the center of the cut is reported to be 25 to 30 feet deep and a small stope is reported to extend southward from the bottom of the shaft. These workings were idle in February 1943 when the property was last visited.

New Idria

Introduction. The New Idria mine is not only one of the deepest and most productive quicksilver mines in the world, but it is also distinguished by having the second largest furnace capacity. In 1941 the four rotary furnaces were treating 400 tons of ore a day and producing the second largest amount of quicksilver of any mine in the United States. Fully three-fourths of the ore treated was being taken from old dumps; the remainder was stope fill and newly mined ore. Since 1941 the New Idria has been the largest single producer of quicksilver in the United States. Most of the ore treated since that time came from recently discovered ore shoots in the eastern part of the mine. Because this ore was rich and because material was nearly exhausted, the tonnage of ore treated in the furnaces dropped markedly. Even so, production from 1942 through 1944 was the greatest in the mine's history.

The mine is developed through a vertical distance of more than 1,400 feet by a maze of drifts and cross cuts that total more than 20 miles in length. Three levels (Nos. 3, 5, and 10) are open to the surface and are connected with the other levels by means of raises and winzes. All workings above the No. 2 level and all evidence of the original outcrops were removed when the large open cut was made. Moreover, all the workings below No. 10 level and parts of the intermediate levels were inaccessible during the present study.

The square-set method of stoping is used almost exclusively though a few small veinlike ore shoots were worked by overhand stull stopes as late as 1940.

Rocks. With the exception of the New Hope vein, which cut Franciscan sandstone on the hanging-wall side of the New Idria thrust fault, all the ore is in an irregular tabular body of Panoche shale and sandstone beneath the thrust fault. Most of the rock is shale, interbedded with thin layers of sandstone (pl. 13), but a thick member of massive arkosic sandstone is present below No. 6 level (see section A-A, pl. 9, fig. 6). Actually the shale in the upper part of the mineralized zone probably belongs below the massive sandstone stratigraphically, but it was pushed upward as a thrust slice to its present position and now rests against overturned beds of shale and sandstone that would, in a normal sequence, be high above it. In much of the ore-bearing zone the beds are overturned and locally are much contorted. In a very general way, however, they parallel the complex hanging-wall surface of the ore deposit.

Rock Alteration. The sedimentary rocks beneath the hanging wall are strongly altered in most places. Above No. 8 level, shale is almost universally indurated but in varying degree, with the strongest induration commonly nearest to the hanging wall. Much of the shale below No. 8 level is nearly unaltered. Sandstone is commonly less indurated than is shale and it is rendered relatively soft and weak by partial alteration of its feldspar grains to clay minerals. Below No. 12 level, however, the sandstone is reported by Lake[22] to be silicified and pyritized although the shale at that level is only slightly indurated.

Pyrite is widely distributed through the altered zone but is nowhere very abundant. Clay minerals, widespread in the altered arkosic sandstones, reach their maximum development in the ''Elvan Streak'' (see pl. 16). This is an irregular, steeply inclined, dike-like body of clayey material that ranges from a few inches to 5 feet in thickness and extends several hundred feet vertically through the western part of the mine. It has been described by several writers as a dike of altered igneous rock, but the field relations and microscopic study convince the writers that it is merely a fracture zone in which the fragmented rocks are thoroughly kaolinized.

The upper, or southwest, side of the altered zone is sharpely bounded in all cases by the fault surfaces that form the effective hanging wall of the deposit. In some places these surfaces are overlain by unaltered Franciscan sandstone or by serpentine on the hanging-wall side of the main New Idria thrust fault. In many places, however, they are overlain by comparatively thin thrust slices of unaltered but strongly sheared Panoche shale and sandstone (see pl. 16, figs. 2, 6). The lower or northeast, side of the altered zone is sharply bounded by a complex, southwestward-dipping footwall fault, underlain by overturned and unaltered Panoche beds, but in a few places the contact with unaltered rocks is gradational.

The indurated rocks are cut by innumerable criss-crossing fractures and fracture zones. Some of these mark faults of slight to moderate displacement but most of them are mere joints. As indicated on plate 16, which shows relations that are typical of the altered rocks throughout the mine, the fractures are much more closely spaced near the hanging wall than elsewhere. These fractures are all closely related both in origin and direction, to late movements along the main faults; so closely related, at least in the western and upper part of the mine, that many

[22] Lake, M. C., op. cit.

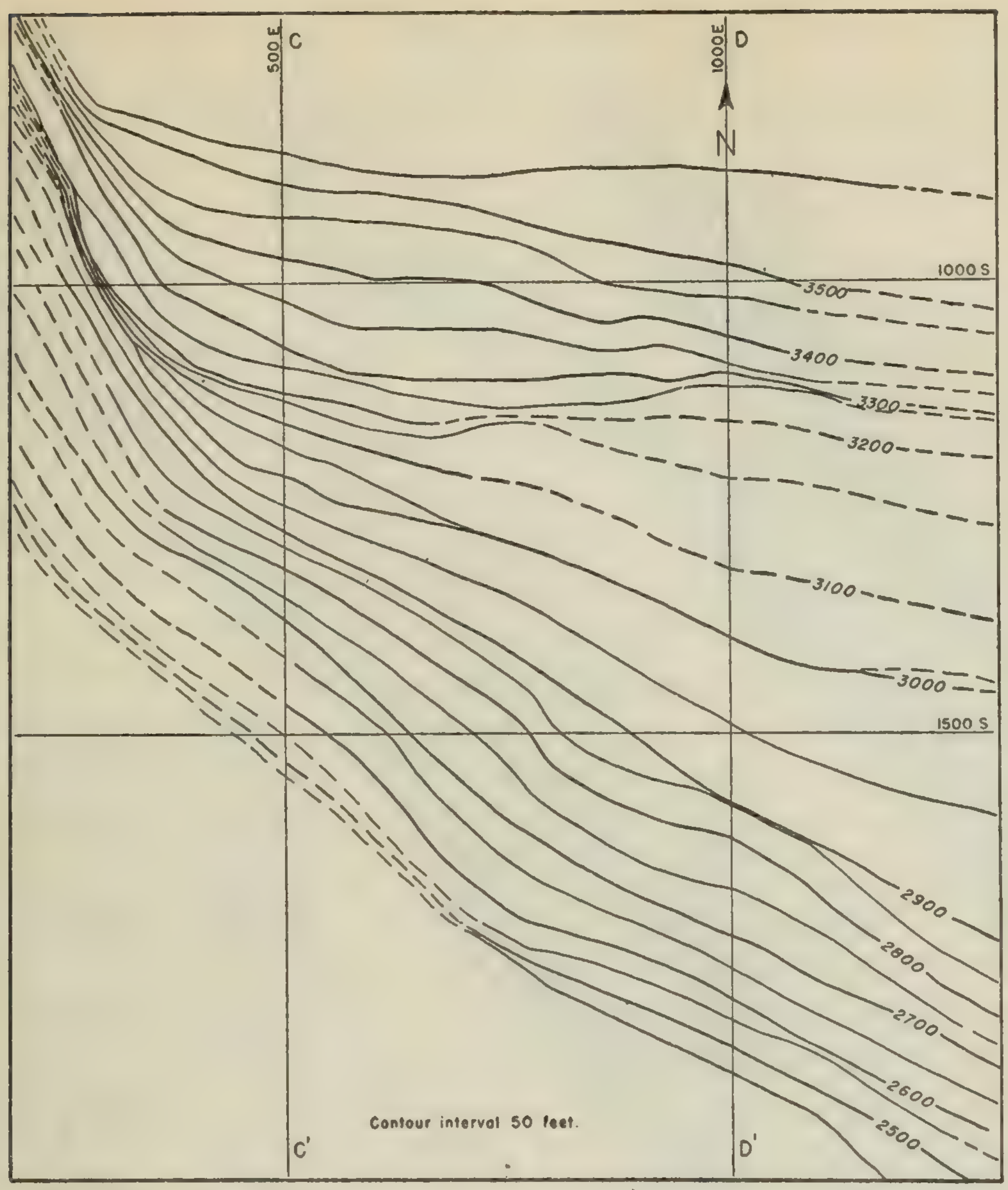

FIG. 2. Contour map of hanging wall, New Idria mine. Sketched from data available in 1941, before new ore shoots in eastern part of mine (pls. 16, 18, fig. 4) were discovered.

irregularities of the main fault plane are directly reflected in the fracture pattern.

Structure. The structural relations are obscure, both on the surface and in the older part of the mine, because of poor exposures, dragging and "churning" of the rocks at fault intersections, and hydrothermal alteration. The early part of this investigation, based as it was on incomplete observations, thus fell far short of providing a clear understanding of the structure. Even so, it permitted valid generalizations as to the structural control of ore bodies and pointed the way to that part of the mine in which high-grade ore bodies were discovered later. Detailed data on the structural relations, as summarized below and shown on plates 16 and 17, and figure 6, resulted largely from day by day observations made during development work both by the operators and by the Geological Survey.

The dominant structural feature of the mine is the hanging wall, which controlled the shape of the altered zone beneath it and of the ore shoots that were deposited in the altered rocks. This hanging wall is a very complex surface, made up of parts of many fault surfaces but, considered as a unit, it consists of a highly irregular, warped surface that dips rather steeply to the southwest. Its general shape, sketched without reference to the different fault planes of which it is composed, is shown by means of contours on figure 2. The footwall of the deposit,

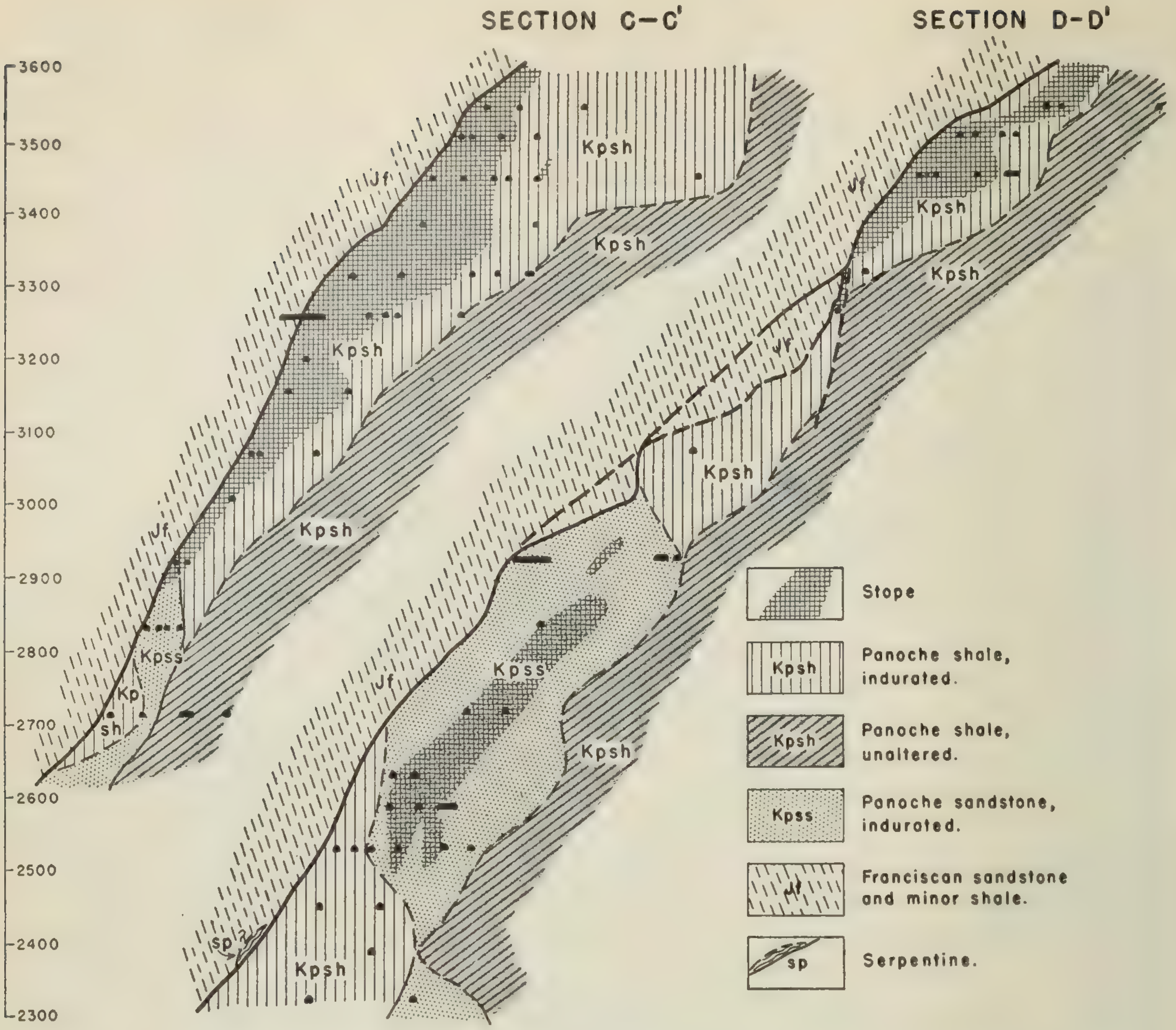

FIG. 3. Generalized vertical sections through the western part of the New Idria mine, San Benito County.

even more complex and less well known than the hanging wall, is roughly parallel to the latter in strike but the hanging and footwalls converge in dip so as to enclose a lozenge-shaped slice of Panoche sediments. This slice, altered and mineralized, contains ore bodies along inverted troughs beneath the warped hanging wall.

The hanging wall of the mine is actually composed of segments of 3 sets of southward-dipping, pre-mineral faults. Most of these are composite and at least one set records recurrent movement. The sequence of faults is as follows:

1. West-northwest-trending thrust fault (''New Idria thrust''); southwest wall moved up and toward northwest.

2. Northwest-trending tear faults (''west of 9,'' Sulphur Spring and other smaller ones); southwest walls moved northwest horizontally.

3. West-northwest-trending thrust faults (renewed movement on New Idria fault).

4. Steep east-northeast-trending normal and reverse faults (''5 east fault''); southeast walls generally moved down and toward northeast.

Though the sequence just given seems to be fairly well substantiated, the relative time interval between the different sets of faults is not known. With the possible exception of the late east-northeast-trending

normal faults, it seems most likely that all of them were formed during the same period of movement and that they actually overlapped in time. Indeed, if the designation of the northwest-trending faults as tear faults is correct, they must, by definition, have developed as part of the thrust movement.

The greater part of the hanging wall of the mine is made up of segments of the main New Idria thrust fault or of parallel subsidiary thrusts which are separated from the main Franciscan-Panoche fault contact by a few feet of strongly sheared Panoche beds. Throughout much of the western part of the mine the average dip of the fault zone is about 55°; in the eastern part it dips about 60° on No. 10 level, but flattens to less than 40° between No. 4 and No. 5 levels (fig. 3, pl. 18).

The north-northwest-trending tear faults which offset the New Idria thrust form comparatively small segments of the hanging wall of the mine. In general they dip much more steeply than the thrust fault. The smallest proportion of the hanging wall is formed by the east-northeast-trending normal faults, which offset all the older faults.

The various faults are marked by 2 to as much as 50 feet of heavy gouge, which contains a few irregular blocks of Franciscan sandstone and of serpentine. It also contains a little cinnabar in places, but all of that seen was definitely deposited after the fault gouge was formed.

The footwall of the mine is gradational in places, but most of it consists of segments of the same sets of faults that have been described above as forming the hanging wall. That is, the inter-relations of the faults are such that the same fault surface may act as the hanging wall in one place and as the footwall in some other place along its dip or strike (pls. 16, 17, 18). Sudsidiary thrusts, form the greater part of the footwall.

Ore Bodies. Some of the ore in the lower part of the mine consists of cinnabar disseminated through sandstone but most of the New Idria ore consists of veins, veinlets, films, grains, and irregular lenses of cinnabar that fill fractures and interstices in indurated and strongly fractured shale. Except for abundant cinnabar, there is to the uninitiated eye little difference between ore-bearing and commercially barren rock. The rocks in and near ore bodies, however, tend to be more minutely fractured and somewhat less indurated than elsewhere, and after long local experience it is generally possible to recognize rock that deserves further exploration or sampling. Within rich ore bodies nearly all fractures contain cinnabar, but in material of lower grade the cinnabar is confined to fractures that trend in only one or two directions (pls. 12, 16).

The general size, shape, and distribution of the ore bodies are shown on plate 16 and figures 3 and 4. Most of them are relatively large and are irregular in outline. In some, this irregularity is due to gradational contacts between commercial and non-commercial ore. Only against the hanging wall are these ore bodies sharply defined and even there a little cinnabar is occasionally present in the fault gouge.

Old mine maps show that the richest ore bodies were distinctly more veinlike than the present stope maps indicate. The two most distinct veins are the above-described Elvan Streak, which is flanked on one or both sides by rich ore in most places, and the now inaccessible New Hope vein. The latter was a northwesterly trending vein in Franciscan sandstone of the hanging wall of the New Idria fault zone. From 1 to 3

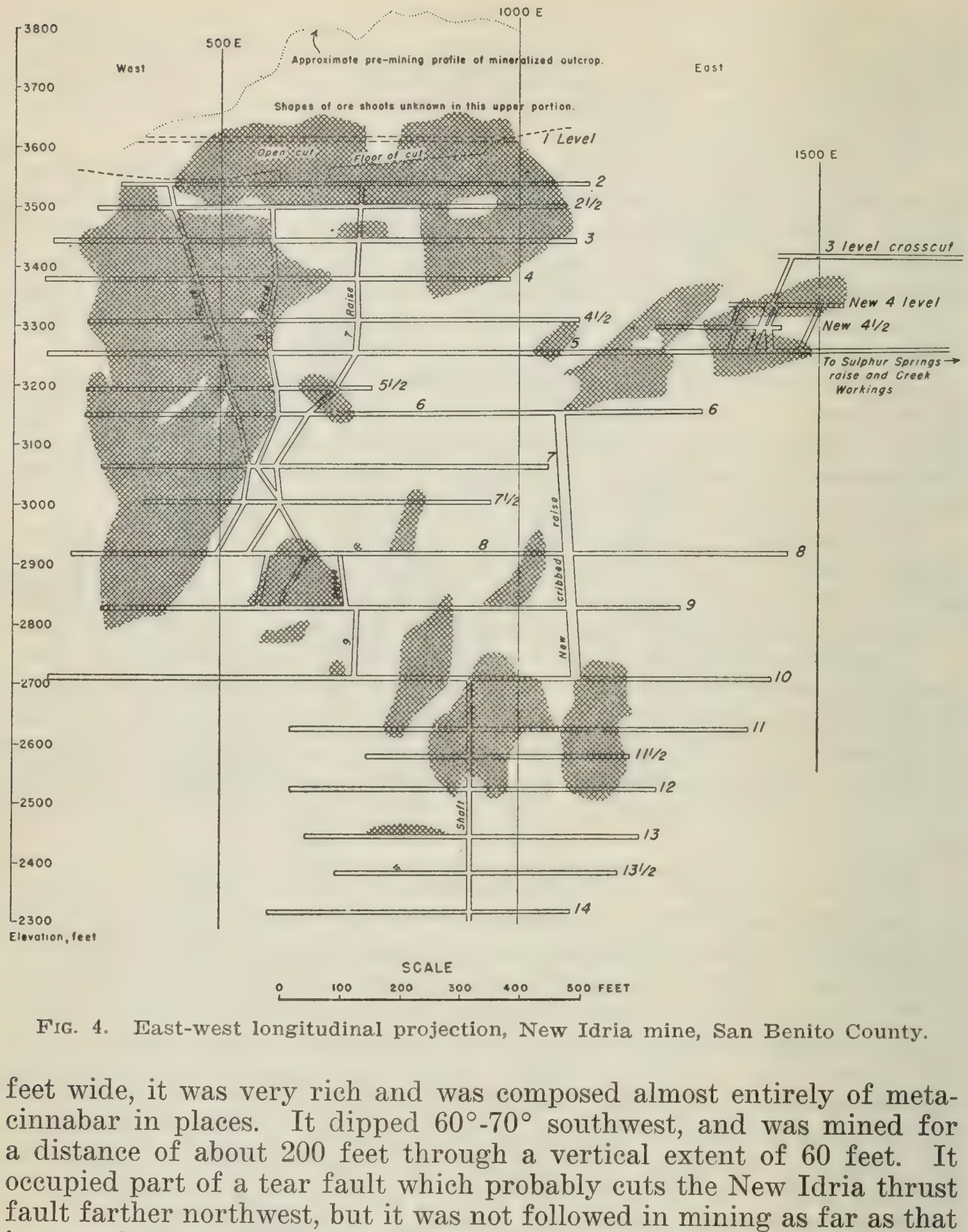

FIG. 4. East-west longitudinal projection, New Idria mine, San Benito County.

feet wide, it was very rich and was composed almost entirely of metacinnabar in places. It dipped 60°-70° southwest, and was mined for a distance of about 200 feet through a vertical extent of 60 feet. It occupied part of a tear fault which probably cuts the New Idria thrust fault farther northwest, but it was not followed in mining as far as that intersection, possibly because the ore body stopped against an extension of the "5 east" fault zone.

Ore has been mined through a vertical range of more than 1,400 feet and a horizontal distance of nearly 1,000 feet. The largest and richest single ore shoot, which occupied a steep inverted trough at the intersection of the New Idria thrust fault with the "west of 9" tear fault (fig. 4) was a pipe-like body 800 feet high, 300 feet long, and 25 to 150 feet wide. The one worked by the open cut and the uppermost mine workings was 800 feet long, 150 to 300 feet high, and 50 to 200 feet wide (fig. 4). It was probably controlled in large part by a flattening in the dip of the New Idria thrust fault, but the footwall may possibly have joined the hanging wall above this flat-dipping segment and may also have been a factor in controlling ore deposition. The shoots on the lower

levels were smaller and somewhat lower in grade than those just noted, and their controls are less clear.

The recently discovered ore shoots on the 4th, 5th and 6th levels in the eastern part of the mine are either in or immediately beneath the apex of the indurated body in the southeast block of the ''5 east'' fault zone. They lie under various types of inverted troughs which were formed by sharp changes in attitude of the complex hanging-wall surface or by intersections of hanging wall and footwall surfaces. These shoots extend upward nearly to the local peak, or ''ridge pole,'' of the indurated body (see plates 16, 17, 18, fig. 4).

Outlook. The very extensive and closely spaced workings of the New Idria mine naturally lead to the suppostion that the mine is virtually exhausted. This supposition is doubtless correct for that part of the mine northwest of the ''5 east'' fault and it is almost equally certain that the mine has long since passed its peak. Neverthless, there are reasons to believe that more ore may yet be found below No. 5 level. Considerable quantities of low-grade but minable disseminated ore in sandstone doubtless exist in the lower parts of the mine, particularly between the 8th and 12th levels. From Lake's geologic map [23] of the now inaccessible workings below No. 10 level it appears very probable that workings encounter the two major tear faults that bound the altered area above No. 10 level. Thus it seems unlikely that any large unexplored blocks of favorable ground exist above No. 14 level. Although a small amount of rich ore was stoped on the No. 13 level and some cinnabar was recorded in logs of drill holes extending a short distance below No. 14 level, very little ore was mined below No. 13 level. This seems to be due in part to the fact that below No. 12 level an increasingly large proportion of the workings are in shale stratigraphically below the thick sandstone member which forms the country rock in much of the lower part of the mine (see fig. 3, pl. 18). Below No. 12 level this shale is only slightly indurated and not a favorable host rock, although according to Lake the sandstone is indurated and pyritized. Any workings following the hanging wall below No. 14 level would be entirely in shale which probably would be less thoroughly indurated with increasing depth. Moreover, the structurally favorable zone tapers downward, so that each successive new level would explore less and less ground. If ore does exist at greater depths, it would thus have to be relatively rich to pay for high development and extraction costs.

Molino

The presence of cinnabar in a bold outcrop of indurated Panoche shale between the creek and San Carlos workings has been known since the early days of the New Idria mine; but the Molino workings, which partly explore the ground below this outcrop, had produced little or no ore until the late spring of 1941. The upper working (pl. 19) was driven primarily to provide a haulageway for ore from the San Carlos mine, more than a mile distant. It left the mineralized zone about 400 feet from its portal and thence was driven largely in soft unaltered shale on the footwall side of the New Idria fault (see inset map, pl. 19).

Plates 9 and 16 show the Molino altered zone to be in Panoche shale and sandstone on the footwall side of a major tear fault zone which here

[23] Lake, M. C., op. cit.

trends northwesterly and dips 57° southwest. It cuts off a west-northwest-trending anticlinal structure in the Panoche beds, which together with several minor faults, localize the alteration. The intersection of the more westerly trending structures in the Panoche beds by the more northerly tear fault zone has produced a sharp bend in the altered outcrop.

The strongly indurated shale and sandstone are cut by closely spaced fractures, some of which contain fairly abundant cinnabar. Pyrite and marcasite are more widespread and plentiful than elsewhere in the New Idria-San Carlos belt. The majority of the fractures strike in a northerly direction or oblique to the main fault, and dip west at variable angles.

Too little is known of the Molino to justify confident predictions as to its future, but at least it seems to deserve further exploration. In June 1941, open-cut operations were begun on the outcrops near the portal of the upper level and northwestward along the hanging-wall fault. Some of the material was found to be of commercial grade and several hundred tons of fair ore was furnaced. No further work has been done since 1941 however, and no information was available in April 1945.

San Carlos

The San Carlos deposit was discovered in 1858 and is reported to have produced 60,000 flasks of quicksilver though detailed records are lacking. In the period 1916-1917 a small amount of ore was mined by underground methods, and the extensive waste dumps were screened for the fine ore they contained. According to old records, portions of these dumps had already been worked in earlier years. From the fall of 1941 to the fall of 1943 the waste dumps were again reworked by the present operators. Those parts of dumps that contained two pounds or more of quicksilver to the ton were transported two miles to the New Idria furnaces over the San Carlos aerial tram.

The open cut, from which all but a small fraction of the ore was taken, is shown on plate 9. This cut is roughly 600 feet long, 300 feet wide and more than 100 feet deep in places. The underground workings are shown on plate 20.

The San Carlos ore deposit is in moderately argillized and indurated sandstone and shale of the Panoche formation along the western boundary of a large but thin tabular lens of intensely indurated and silicified Panoche shale. The beds are overturned through a distance of nearly 1,000 feet from the fault and dip at moderate angles to the south and southeast (see pl. 9).

The hanging wall of the deposit is a segment of the New Idria thrust fault which here trends about N. 65° W. and has an abnormally low south dip. The fault flattens upward and locally it even dips north at very low angles (see pl. 11). In the vicinity of the indurated lens the hanging-wall block of the thrust is a fault-bounded tabular body of serpentine caught in the New Idria fault between the footwall Panoche sediments and the Franciscan sandstone which forms the hanging wall of the thrust in most places. This serpentine extends along the strike of the thrust for nearly 4,000 feet and locally is at least 200 feet thick. It has been converted in places to silica-carbonate rock by the hydrothermal solutions which also altered and indurated the Panoche sedi-

ments. This silica-carbonate rock contains cinnabar at a few places and parts of it over the site of the open cut contained enough cinnabar to be mined. Much of the nearly flat plate, or fault slice, has been removed by erosion and by mining operations but several small remnants are still present and give evidence as to the original position and shape of the thrust fault. Much of the fault movement was taken up by shearing in the serpentine; the silica-carbonate rock preserves strong linear textures parallel to the contact, whereas only the uppermost layers of the underlying Panoche beds are strongly brecciated.

The footwall of the indurated, ore-bearing shale lens at San Carlos trends toward the west and dips south at moderate angles. The few available underground data, as well as relations shown on old company maps lead to the belief that the footwall is determined by a fault or fault zone in most places, although rock alteration, controlled partly by later faults, deviates locally from this postulated fault surface. The best evidence is on No. 3 level near the shaft, where a 2-foot zone of fault gouge strikes N. 85° E. and dips 33° south. The shaft is caved at the point where the fault should be exposed but the caved ground itself provides indirect evidence that the rocks beneath the gouge zone are soft shale rather than the indurated rock above the footwall. This fault, if it continues its observed attitude, is in the correct position to act as the footwall for the entire lens. It is probably related to the New Idria thrust, both in time and origin, though its attitude is similar to that of some subsidiary branches of the later "5 east" fault zone in the New Idria mine. Possibly it is a subsidiary thrust formed below the New Idria thrust where the anomalous flattening of the latter caused a concentration of stresses.

The western boundary of the deposit is formed by a northwest-trending tear-fault zone which offsets the older New Idria thrust fault to the north. Individual faults of this zone range in strike from N. 6° W. to N. 40° W. and in dip from 45° west to 66° east. This compound zone may be divided on the surface into three branches. The easternmost is made up of relatively weak faults which together offset the New Idria thrust fault nearly 200 feet. The intersections of these faults and the New Idria thrust form the control for the greater part of the ore mined at San Carlos. The central branch, represented over much of its surface trace by a single vertical fault striking N. 30° W., forms the west boundary of the explored deposit. It offsets the New Idria thrust about 500 feet, bringing serpentine in the west block in contact with the Panoche rocks along the entire west boundary of the deposit. At depth this fault is believed to be represented by several fault planes which control a nearly vertical slice of indurated and locally metallized Panoche sediments, that extends at least as far down as the Molino adit (elevation 3907 feet), a depth of about 800 feet from the surface. The western branch, which offsets the New Idria thrust about 700 feet, is a single, steeply east-dipping fault on the surface, marked by 10 feet or more of gouge with fragments of serpentine and Franciscan rocks.

The segment of the New Idria thrust that lies between the central and western branches of the tear-fault zone has not been prospected; the outcropping rocks near it are altered to clay but are not indurated.

In the immediate vicinity of the open pits the Panoche beds beneath the New Idria thrust include both sandstone and shale. They are much less thoroughly indurated, but more thoroughly argillized, than most of

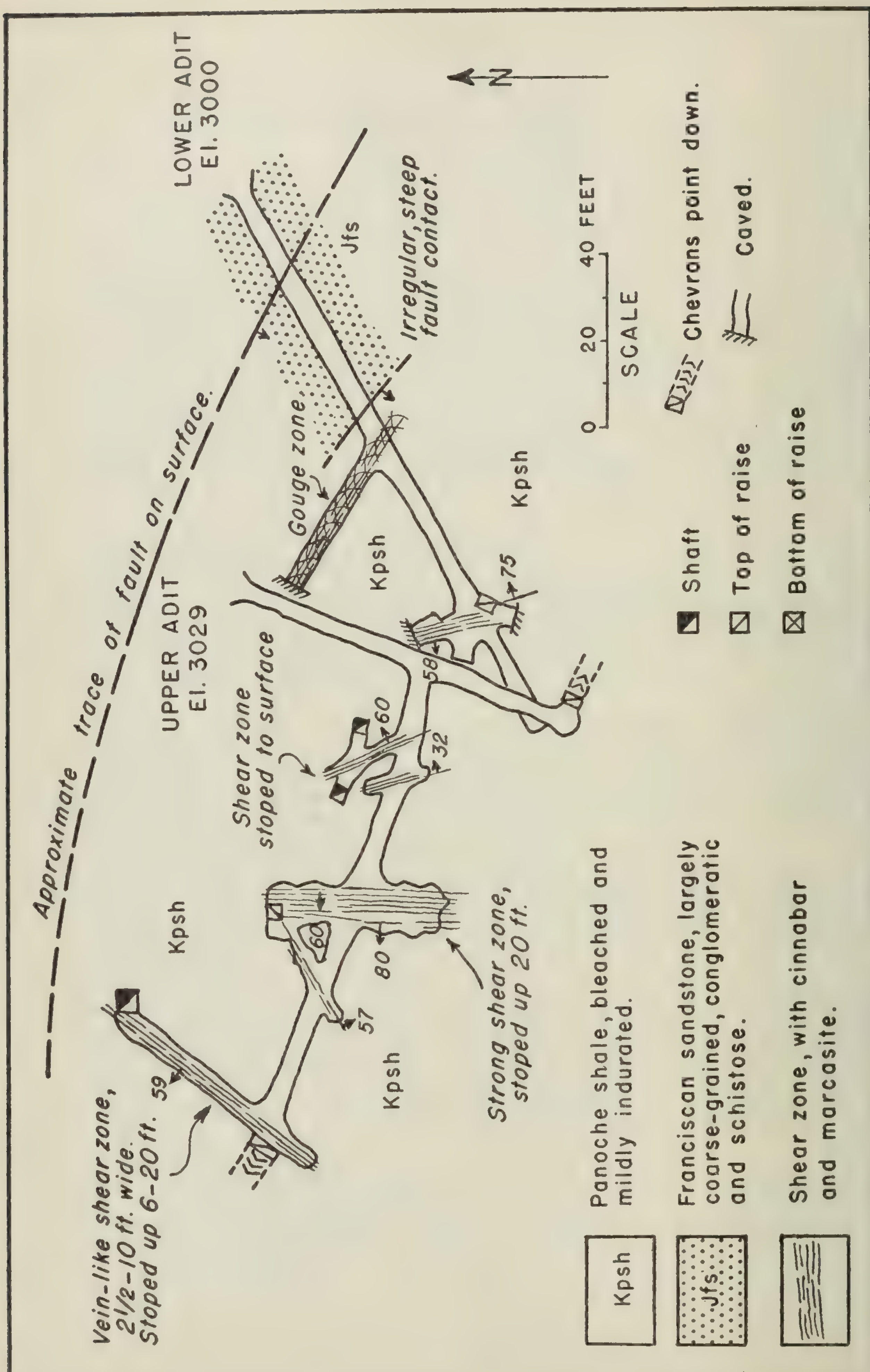

FIG. 5. Geologic map of principal workings, Florence Mac mine, San Benito County.

the similar sediments in the New Idria deposit or in the barren, highly indurated lens immediately southeast of the San Carlos deposit. It is noteworthy that this deposit is confined almost exclusively to a zone where the rocks were not nearly as hard and brittle as are those a short distance to the east. Apparently the structural control and the solution-way along the tear fault zone were more important to the deposition of cinnabar than was a large and immediately adjacent area of easily brecciated rocks.

The main ore body worked by the open pit is cut by great numbers of steeply inclined fractures and by several faults of small displacement which strike from N. 10° E. to N. 45° W. Cinnabar is widely distributed along nearly all the fractures in the mineralized zone. Many fractures contain veins of coarsely crystalline comb quartz, some of it amethystine, which contain blebs and crystals of cinnabar between the quartz crystals. Cinnabar also cements some shattered quartz crystals. In addition to the ore body in altered sedimentary rocks, the silica-carbonate rock that formerly capped the deposit locally contained much cinnabar. This ore did not differ appreciably from that in other silica-carbonate bodies. Much of the ore produced in 1916-1917 was in the form of blocks of cinnabar-rich silica-carbonate rock that had broken from the outcrop and slid down the northeast side of San Carlos Peak.

The accompanying maps (pls. 9, 19, 20) together show that the San Carlos ore body was nearly horizontal and that it has been pretty definitely bottomed, for very little commercial ore has been found in any of the fairly extensive underground workings.

Sulphur Spring-Creek

The altered zone partly developed by the Sulphur Spring and Creek tunnels, part of the New Idria property, has yielded comparatively little ore of commercial grade, but the geologic relations are so similar to those in the New Idria mine that it is considered one of the more promising places in the district for further exploration. The geologic relations are shown on plates 9 and 17. On plate 9 it can be seen that between the two tunnels the hanging-wall fault swings abruptly from a N. 70° W. course to N. 20° W. The dip also changes abruptly for it is 65°-70° south near the Creek workings and 30° west in the Sulphur Spring workings. As in the New Idria mine the hanging wall owes its shape to various segments of the westerly trending New Idria thrust and of north-northwest-trending tear faults.

Within the inverted trough formed by the bend in the fault, the overturned Panoche beds are thoroughly indurated and are cut by innumerable late fractures, many of which contain small quantities of cinnabar. Most of the rock explored by the Creek workings, both surface and underground, is sandstone; that in the Sulphur Spring is largely shale interbedded with some sandstone.

Other Mines

The *Del Mexico* consists of a series of parallel, vertical veins that cut a wedge-shaped body of indurated sandstone above unaltered Panoche shale and beneath the New Idria thrust fault (see fig. 6). The rocks are by no means as thoroughly brecciated as those at New Idria and the veins are very narrow in most places. Their probable intersections with the main fault have not been explored.

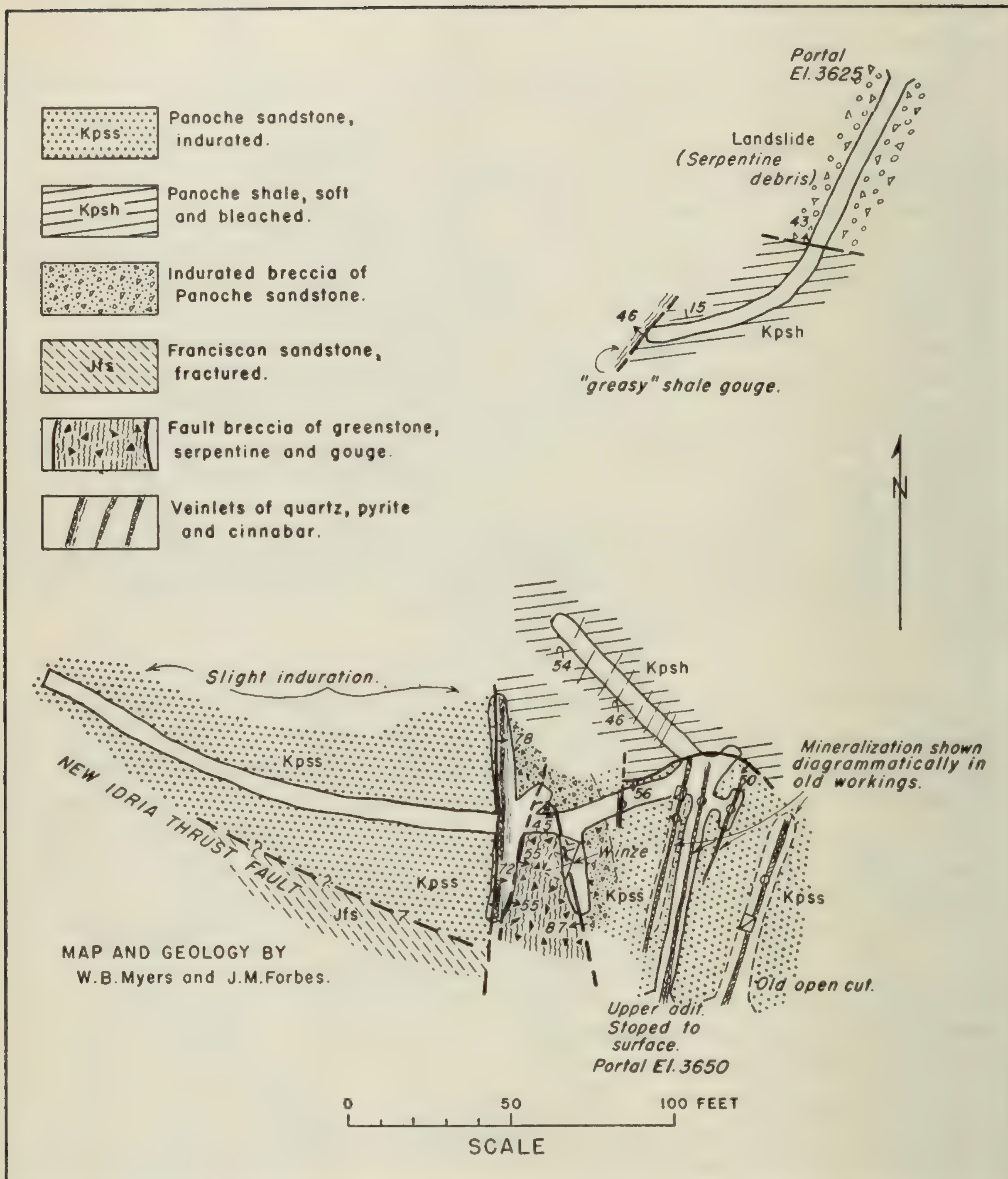

FIG. 6. Geologic map of Del Mexico mine, Fresno County.

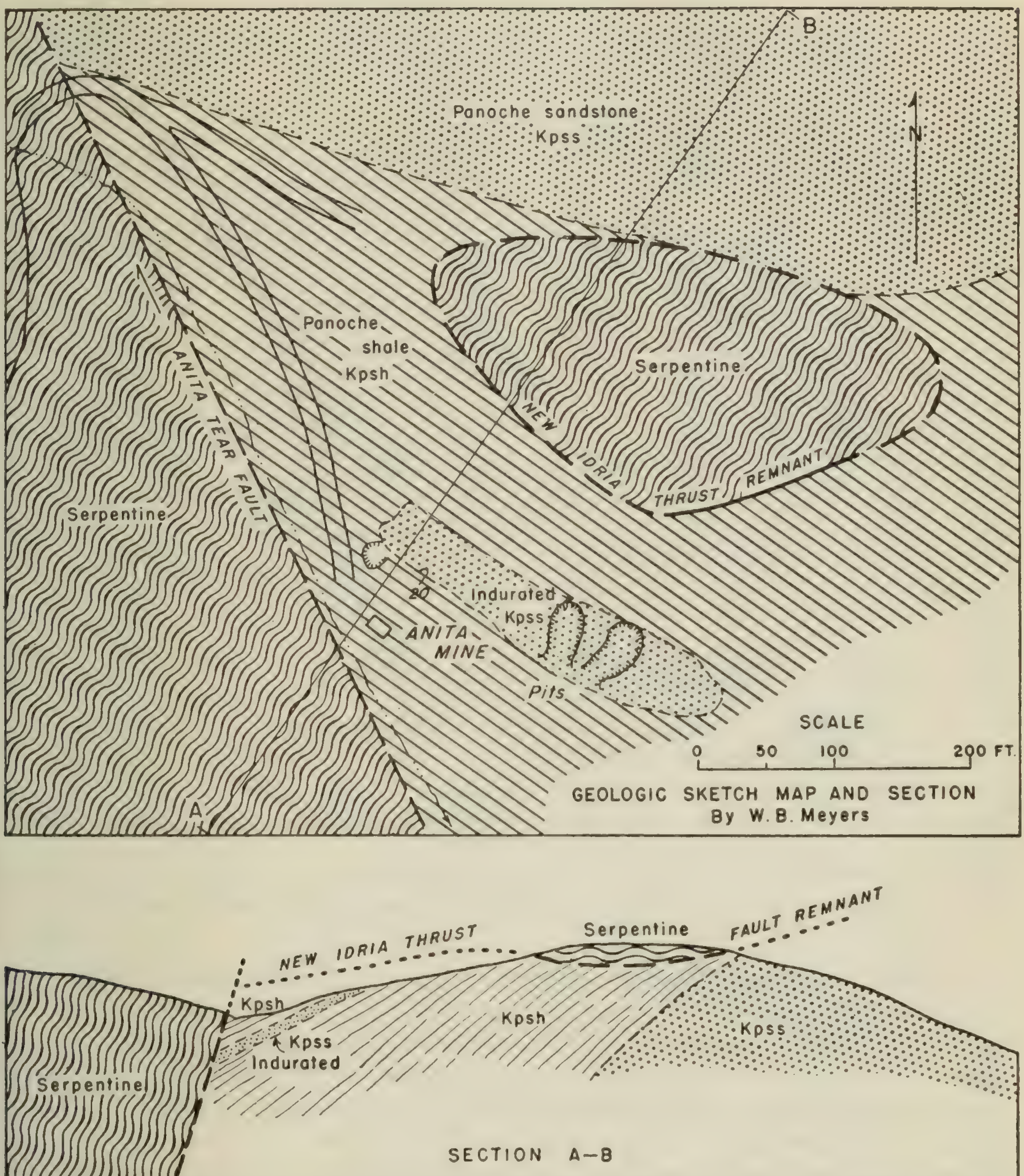

FIG. 7. Sketch plan and section of the vicinity of the Anita quicksilver mine, Fresno County.

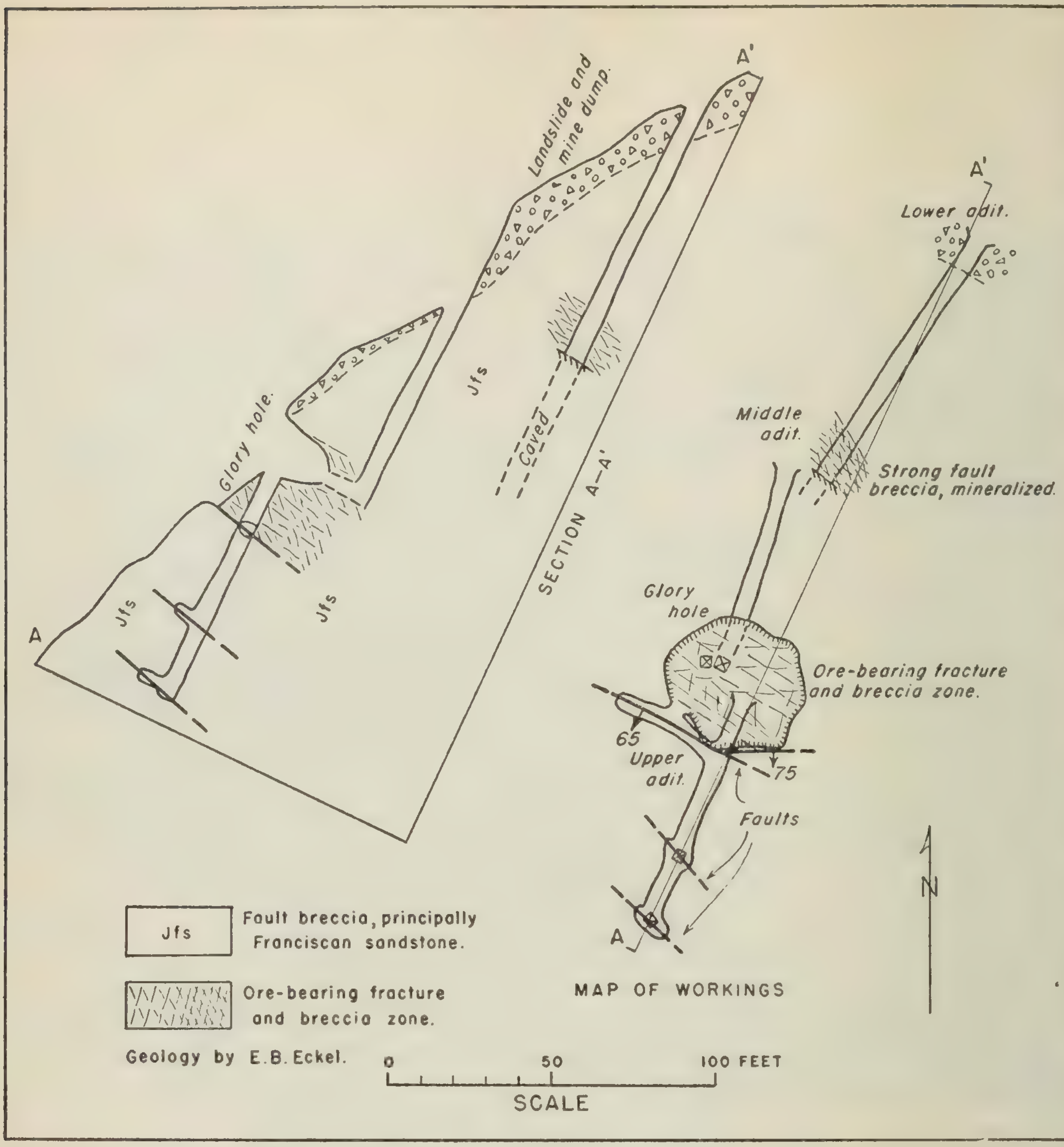

FIG. 8. Map and section of the Wonder mine, San Benito County.

The *Anita,* first known as the Chiquita, and later as the Rita, is in an indurated bed of Panoche sandstone, 6-7 feet thick, interbedded with overturned and unaltered shale in a structural setting much like the San Carlos deposit (see fig. 7). Cinnabar occurs as small blebs and bunches accompanied by some quartz in late fractures and faults of very small displacement. The mined ore is reported to contain about 10 pounds of mercury per ton. A small amount of pyrite is scattered throughout the sandstone. No cinnabar was seen in the enclosing unaltered shale. In February 1943, all production had been from workings a few tens of feet below the serpentine thrust plate which appears to have capped the deposit.

As shown on plate 8, the *Breen, Florence Mac (Florence Mack), New Tirado* and several other deposits of minor significance are in altered Panoche shale above normal faults along the south and west side of the New Idria dome. They differ from the Archer mine only in detail. The geology of the Florence Mac mine, the only one of these which has pro-

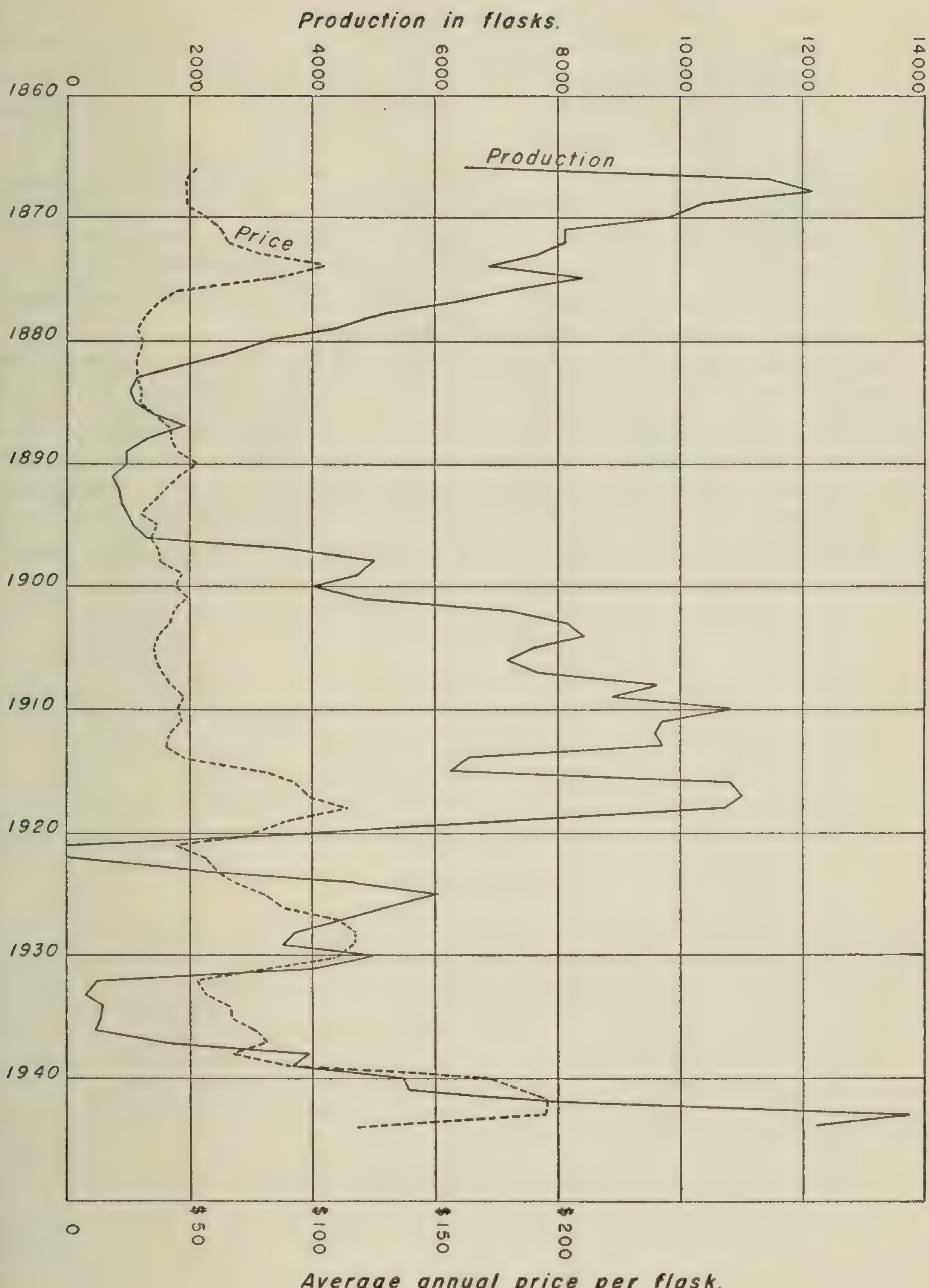

FIG. 9. Curves showing relationship between quicksilver prices and production of New Idria mine, 1866-1944.

duced appreciable amounts of quicksilver, is shown on figure 5. The shale there is much less thoroughly indurated than that at the Archer and the ore is commonly less rich, but otherwise the deposits are strikingly similar.

The *Alpine, Picacho* and the various members of the *Flint group,* as well as several relatively unimportant prospects, are similar in most respects to the Aurora mine described above. All those mentioned are in the northwest part of the district (pl. 8) on a broad indefinite shear zone in serpentine which contains many lenses and irregular bodies of silica-carbonate rock. Most of these bodies are very shallow and nearly all the ore produced has been taken from open cuts or from boulders on the surface. The shallowness of most of the bodies and the failure of several extensive exploratory adits to encounter anything but unaltered serpentine is explained by the fact that the enclosing shear zone dips to the southwest at low angles. Many of the tabular outcrops thus represent discontinuous remnants perched on the hill slopes.

The *Wonder* mine differs from all others in the district in that it lies in a crushed zone on the hanging-wall side of the New Idria fault and between it and a strong tear fault (pl. 9). As indicated on figure 8, the country rock is thoroughly brecciated sandstone of the Franciscan formation. Most of the late fracture zones, some of which contain cinnabar, strike east and dip south, and are thus roughly parallel to the New Idria fault at this place. The deposit has not been sufficiently explored to determine its extent or possible worth.

QUICKSILVER DEPOSITS AT THE SULPHUR BANK MINE LAKE COUNTY, CALIFORNIA*

By Donald L. Everhart**
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

ABSTRACT

The Sulphur Bank mine lies at the end of the east arm of Clear Lake, Lake County, California, about 13 miles by road north of the village of Lower Lake. Opened in 1865 as a sulphur mine, it began producing quicksilver in 1873 and operated continuously to 1903. World War I caused it to be worked from 1915 to 1919, and the present period of production began in 1927. Up to the end of 1944 the mine had yielded 126,285 flasks of quicksilver.

The rocks exposed in the open pits of the mine are divisible into three geologic units. The oldest, which belongs to the Franciscan group, of Jurassic (?) age, is represented at the mine by sandstone and shale but includes some greenstone and chert nearby. The Franciscan rocks are unconformably overlain along the lake shore, at the base of an east-trending ridge, by an irregular lens-shaped body of Recent landslide breccia, interbedded with lenses of lake-laid conglomerate and sandstone. These are in turn overlain by a Recent flow of augite andesite, most of which is altered in the vicinity of the mine.

The rocks are cut by two major sets of faults, which are largely confined to the Franciscan rocks. The main fault zone trends about N. 70° E. and dips from 50° SE. to vertical, and it may be paralleled by a concealed fault zone about 500 feet to the north. It is intersected by a set of northwest-striking faults, dipping steeply north-

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** Geologist, U. S. Geological Survey.

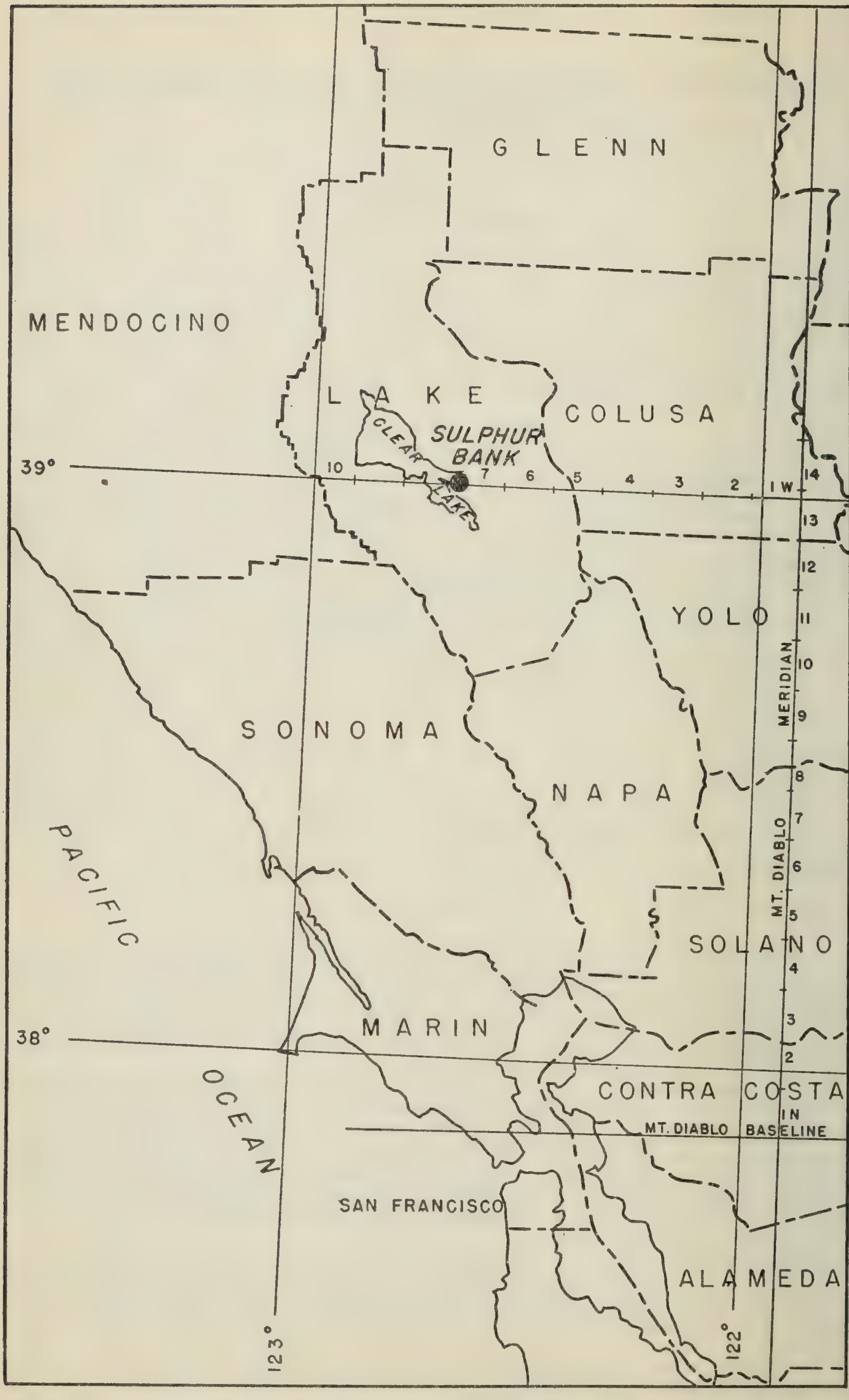

FIG. 1. Index map of central California showing the location of Sulphur Bank mine, Lake County.

east to vertical, which originated before the Recent epoch but along which recurrent movement has caused small displacements and flexures in the andesite flow.

Hydrothermally altered rock, hot springs, and small fumaroles are widespread along the fault zones and at their intersections. Different rocks are differently altered; Franciscan rocks in the fault zones are carbonatized whereas the Recent sediments and the lava flow are kaolinized. These alterations were followed by deposition of cinnabar and pyrite. Still later, stibnite, various sulfates, and flour sulfur appear to have been precipitated at the orifices of the fumaroles and near the hot springs by waters and gases similar to those now issuing from them. The andesite flow is capped, at Sulphur Bank, by 25 feet of white, powdery, opaline silica, in the open spaces of which gypsum and free sulfur have been deposited. This cap was formed by leaching of the andesite flow by sulfuric acid and reprecipitation in the open spaces.

The ore bodies are structurally controlled by the fault zones and their intersections, but their character varies with the country rock. Those in the altered andesite consist of high-grade stringers, associated with clays, along jointing and sheeting planes. Those in the Recent sediments consist of fine-grained cinnabar, also associated with clays, filling open spaces in breccia and conglomerate; these bodies commonly widen and flatten below the contact with andesite. In the Franciscan rocks the cinnabar coats blocks of sandstone in the fault breccias and is finely disseminated in the gouge. In these rocks the ore shoots are closely controlled by the fault intersections and have the form of steeply pitching pipes.

Ore has been mined in recent years from seven connected open pits, covering an area of 1,570,000 square feet. Early operations were carried on through four major and three minor shafts, but underground methods were given up because of intense heat and gases.

Economic studies have shown that the mounting costs of open-pit mining demand a floor price of $200 per flask for continued successful operation, and even at this high price, no assured ore was in sight at the end of 1944. Indicated reserves total 18,420 flasks from about 115,000 tons of ore, and 15,750 flasks may be obtainable from 150,000 tons of inferred ore.

INTRODUCTION

Location

The historic Sulphur Bank mine is at the end of the east arm of Clear Lake, in Lake County, California (see fig. 1). It is reached by 2 miles of well-graded gravel road, which joins California State Route 20, a paved road, 11 miles from the village of Lower Lake, to the south, and 21 miles from Lakeport, to the north. The open pits of the mine lie along the base of an east-trending ridge at the lake's edge, in sec. 6, T. 13 N., R. 7 W., Mount Diablo meridian. Approximately 800 acres of surrounding land are held by the present operators. Flat grasslands with scattered clumps of live-oak trees lie adjacent to the mine workings along the lake shore. To the south they are succeeded by the rolling wooded hills immediately behind the plant and camp, and these hills merge with a steep, brushy ridge.

Previous Work

Ever since its discovery, Sulphur Bank has received much attention in the geologic literature. A list of the principal reports dealing with the Sulphur Bank mine is given below. Many of these reports have supplied historical information used in this report. The deposit is also mentioned in nearly every textbook on metalliferous ore deposits, because of the close association between the hot springs of the district and the cinnabar; it has even been supposed, in the writer's opinion erroneously, that the hot springs are depositing cinnabar at the present time.

List of Publications

California State Mining Bureau
Reports IV pp. 157, 330, 336, 339
V p. 96
VI p. 136
(Pt. 1)
VIII p. 324
X pp. 238-239
XI p. 63
XII p. 363
XIII p. 597
XIV pp. 234-238, 240
Chapter rep. bien. period, 1913-1914, pp. 62-66, 68
Bulletins 27 pp. 61-70
78 (1918), pp. 63-68
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Calif. Jour. of Mines and Geology, vol. 35, no. 4 (Ransome and Kellogg, 1939), pp. 395-400.
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Monograph XIII, Becker, 1888, pp. 251-270, 463.
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1883, pp. 394-397
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1902, pp. 251, 252
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Geological Survey of California, Geology, vol. I, p. 99
Transactions, A. I. M. E.
XXIII pp. 225 et. seq.
XXXIII p. 751
Series of Ore Deposition, pp. 32, 66, 256
Am. Jour. of Sci., vol. XXIV, 3rd Series, pp. 23 et. seq.
Geol. Soc. of Am. Bull. vol. 47, no. 5 (C. A. Anderson, 1936), pp. 649-654

Field Work and Acknowledgments

The writer spent 3½ months, from mid-March to the end of June 1943, in studying and mapping the open pits of the Sulphur Bank mine and about one square mile of the surrounding area. The geology was plotted on a topographic base map (pl. 21) having a scale of 200 feet to the inch and a contour interval of 5 feet, prepared with a stereo-comparagraph by the Aero Service Corporation, of Philadelphia, from low-flight airplane photographs. W. Bradley Myers of the Geological Survey, U. S. Department of the Interior, furnished the necessary vertical control by leveling, in November 1942. Owing to large changes later caused by rapid mining and development work, the topography of the Herman, Wagon Springs, and Parrott pits and adjacent areas was re-mapped by the writer, by the plane table method, in June 1943.

The main purpose of the project, which was set up by the Geological Survey as part of its program of strategic-mineral investigations, has been to determine the geologic control of the quicksilver ore bodies, and to estimate as closely as possible the mine's reserves and possibilities for future production under varying economic conditions. The writer is acutely aware that the study of Sulphur Bank has brought up scientific problems of ore genesis and mineralogy that, because of inadequate time in the field and particularly in the laboratory, must go unanswered in this report. He hopes that at some future time he may undertake a detailed study of the ore genesis, the hot springs, the gas emanations, and the mineralogy of the sulfates and hydrothermal clays at Sulphur

Bank. Such a study ought to include the mapping of many square miles adjacent to the southern part of Clear Lake.

The work was greatly facilitated by the constant hospitality and cooperation of the Bradley Mining Co., the present operators of the Sulphur Bank mine. Mr. Worthen Bradley, president of the company, and Mr. Albert F. Wolbert, mine superintendent, gave freely of their time and resources, and the writer is particularly grateful to them for the services of a rodman during one week in June 1943. W. Bradley Myers of the Geological Survey, who was doing field work in the nearby Wilbur Springs district at the time of this investigation, gave help and many valuable suggestions during field work. E. B. Eckel, as counselor for the project, also deserves the writer's thanks. Facilities for study of part of the thin sections were kindly afforded by the University of California at Berkeley.

HISTORY AND PRODUCTION

As the name implies, the Sulphur Bank mine was first worked for native sulfur deposited near the surface. Sulfur mining was begun by the California Borax Company in 1865 and abandoned in 1868. A fall in the price of sulfur, combined with difficulties in refining caused by the cinnabar content of the rock 15 to 25 feet below the surface, caused the shutdown, but only after 2 million pounds of sulfur had been produced from open pits.

The quicksilver boom of the 1870's converted the cinnabar into a valuable asset, and it was mined for the first time at Sulphur Bank in 1873. Quicksilver mining was carried on by the California Borax Company until 1883, during which time the Herman shaft was sunk. In 1887 the Sulphur Bank Quicksilver Mining Company reopened the mine, which it operated for 10 years, sinking the Diamond and Babcock shafts as well as expanding the open cuts worked by the California Borax Company. It was during this period that George F. Becker[1] made his famous study of the mine and of the whole Clear Lake area. Work in the mine was described in those early days as being extremely unpleasant, owing to heat, acrid dust, and suffocating gases. Apparently almost all the mining was performed by Chinese labor, because white men refused employment.

In 1899 the mine was taken over by the Empire Consolidated Mining Company, which worked it on a reduced scale until December, 1905, and kept the shafts unwatered until June, 1906. By this time sulfur dioxide and heat had rendered underground mining so difficult that it was entirely abandoned, and since then it has not been attempted on any significant scale. Before the mine was closed, men worked in 20-minute spells, while being constantly sprayed with water.

In 1915 the property was acquired under lease and bond by the Sulphur Bank Association, of San Francisco, which carried on surface work until the end of 1919. A rotary furnace was installed in 1918, replacing the Knox-Osborne and Scott furnaces and D retorts previously used.

The period of idleness following World War I was terminated by the present period of open-pit mining, which was begun in 1927 and was still being carried on in the middle of 1945. The mine property is now

[1] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mono. 13, pp. 238-239, 1888.

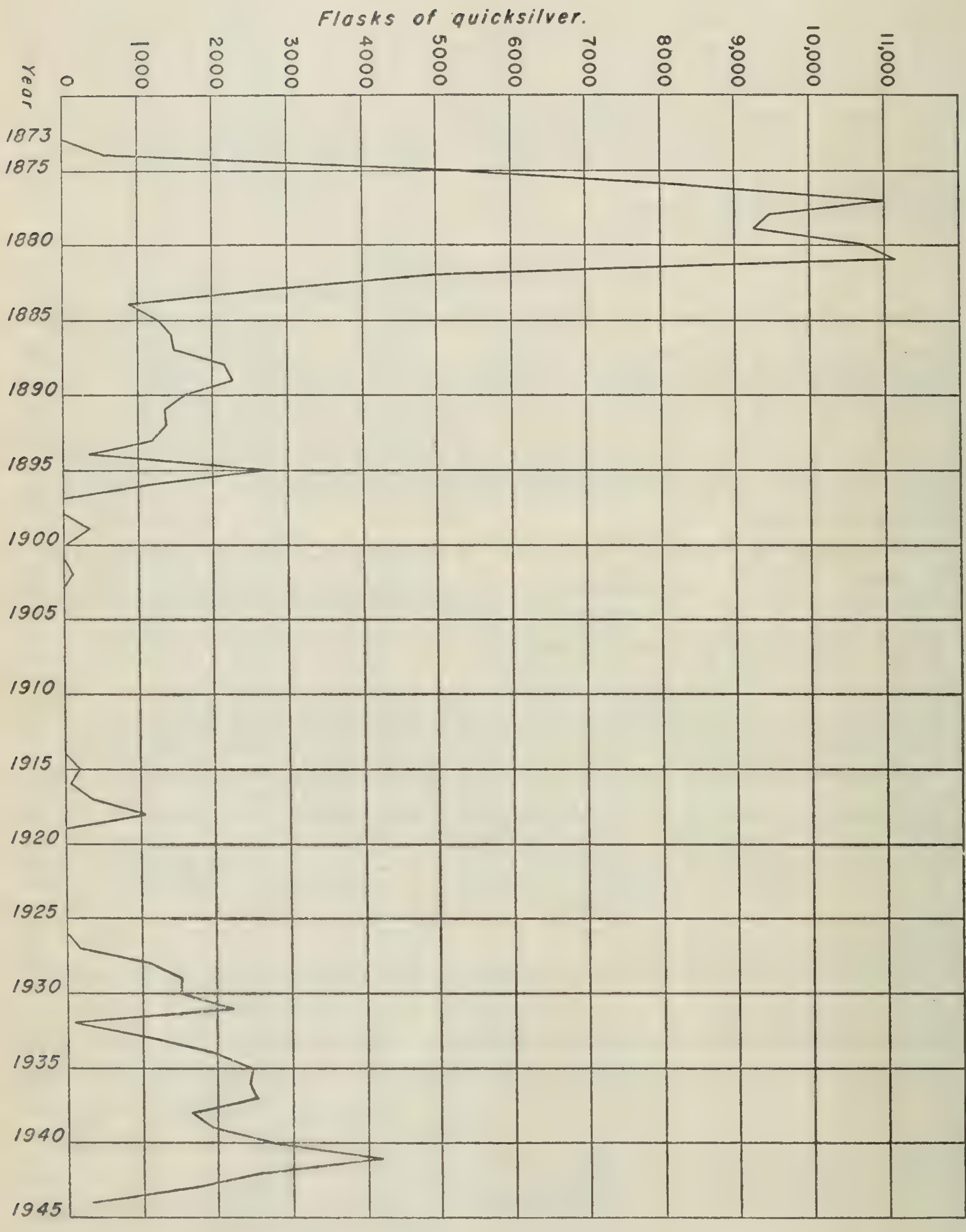

FIG. 2. Annual production graph of the Sulphur Bank mine, Lake County, 1873-1944.

part of the estate of G. T. Ruddock, and is leased and operated by the Bradley Mining Company of San Francisco.

Up to the end of 1944 Sulphur Bank had produced 126,285 flasks of quicksilver, most of it during the early periods of production (see fig. 2).

GEOLOGY

General Sequence of Rocks

The rocks exposed in the open pits of the Sulphur Bank mine and in the adjacent area may be divided into four units, which in ascending order are: (1) rocks of the Franciscan group, (2) Recent brecciated rocks, conglomerate and sandstone, (3) a Recent flow of augite andesite, and (4) post-andesite sediments consisting mostly of modern lake deposits.

The oldest rocks in the district are sandstone and shale of the Franciscan group of Jurassic (?) age. No other Franciscan rocks are exposed in the open pits, but small, irregular, discontinuous bodies of greenstone and chert crop out on the high ridge to the south. In the pit area, the Franciscan rocks are unconformably overlain by a lens-shaped body of Recent sediments, which varies greatly in thickness. In a large part these sediments are breccia consisting of sandstone and shale of the Franciscan group. The breccia is thought by the writer to be of landslide origin. Conglomerate and sandstone beds occur toward the lakeward extremities of the lens and apparently represent near-shore facies of lake-laid sediments. A recent flow of augite andesite, in large part altered, overlies the Franciscan and Quaternary (?) deposits. It covers no more than a square mile, and its highest exposures are only 1,430 feet above sea level, or about 105 feet above the mean level of Clear Lake. Lake deposits of recent age are exposed in the inlets of the lake shore and overlap the lava flow, reaching an altitude, in places, of about 60 feet above the present level of the lake.

Franciscan Group

The sandstone of the Franciscan group varies markedly in character from place to place within the area mapped. This rock has all been subjected to mild dynamic metamorphism; fault movements have sheared it in certain zones, and almost everywhere in the Sulphur Bank mine area it has undergone hydrothermal alteration. Comparatively fresh sandstone is exposed, however, in parts of the ridge back of the mine and in some of the fault blocks exposed in the bottom of the pits. This rock is medium-grained and massive and is largely arkosic. In thin section the less arkosic phases are seen to consist mainly of irregular, medium-sized quartz grains, the interstices between which are partly filled with granulated quartz. A few grains of what appears to be biotite are present, and pyrite and a little magnetite fill some fractures and interstices. The more arkosic phases also consist largely of quartz but contain up to 40 percent of feldspar in irregular grains. Orthoclase and sodic plagioclase are about equally represented. The orthoclase is largely sericitized. The slightly metamorphosed sandstone that underlies much of the area is grayish-green to brownish-green in color and is medium-grained and somewhat porous. In thin section, it can be seen that the interstices between quartz and altered feldspar grains are partly filled with abundant chlorite, a little epidote, and limonite derived from pyrite and magnetite.

The sandstone is interbedded with, and grades into, fine-grained black shale. The relations between these rocks are so complex that the two cannot be represented in detail on the scale of the map. An attempt was made, however, particularly in the vicinity of the pits, to distinguish areas chiefly underlain by sandstone from those chiefly underlain by shale. In thin section, the typical shale of the Franciscan group is seen to contain lenses and vein-like bodies of clear granulated quartz mixed with a minor quantity of feldspar. Relatively coarse-grained veinlets cut a very fine-grained groundmass, in which there are oriented streaks of sericite and chlorite and considerable dark-brown limonite. Late sulfides and magnetite coat the walls of some open spaces and quartz-lined vugs.

Recent Sediments

Recent sediments unconformably overlie the Franciscan rocks along the base of the ridge in the Sulphur Bank area. The age of these sediments has been subject to some debate in past publications. Forstner[2] correlated them with what Becker[3] described as the Cache Lake beds; Anderson,[4] who called Becker's Cache Lake beds the Cache formation, which he showed to be upper Pliocene or lower Pleistocene in age, agrees with Becker in calling the Sulphur Bank sediments Recent lake deposits, laid down when Clear Lake stood at a higher level. The writer concurs.

The sediments consist largely of poorly bedded, massive conglomerate and breccia, with many lenses of cross-bedded, medium- to fine-grained sandstone. The coarse-grained rocks are very loosely consolidated and are homogeneous in appearance. They are characteristically greenish-gray to light-gray in color and largely made up of blocks of irregularly oriented sandstone and shale fragments of the Franciscan group embedded in a shaly to sandy matrix. The sandstone blocks, which are up to one foot across are commonly angular, though some pebbles in the conglomerate are well rounded. Parts of the deposit exhibit features that strongly suggest landslide material. These features include association of sandstone blocks that differ widely in size, irregular orientation of the blocks as shown by their bedding planes, and apparent lubrication of the sandstone blocks by a shaly matrix, which itself shows crumpling and contortion such as would be caused by sliding. The view that this formation is in part a pre-andesite landslide is further supported by its bulbous shape. The presence, however, of many small pinching and swelling sandstone lenses and beds of pebbles that are obviously water-worn indicates that the formation consists in part of sediments deposited in the lake.

The sediments enclose many fragments of wood, most of which are only a few centimeters across where exposed. One fragment, however, that was found by the writer measured 18 by 4½ inches on the exposed face. Wood from these fragments has been identified as *Sequoia sempervirens,* which could be of either Pleistocene or post-Pleistocene age.[5] Deformation of the waterlogged wood in place has commonly given the fragments a schistose texture, but under a binocular microscope a few

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[2] Forstner, Wm., The quicksilver resources of California: California Min. Bur. Bull. 27, pp. 64-65, 1903.
[3] Becker, G. F., op. cit., pp. 238-239, 1888.
[4] Anderson, C. A., Volcanic history of the Clear Lake area, California: Geol. Soc. America Bull. vol. 47, pp. 639, 1936.
[5] Personal communication from Roland W. Brown, National Museum.

pieces clearly show the cellular structure of redwood. Becker[6] noted other plant fragments, which he identified as tule roots (*Scirpus lacustris*) "strongly resembling Caulinites." Most of the plant fragments are charred, probably by the action of sulfuric acid, to such a degree that they resemble charcoal.

The entire unit as exposed at Sulphur Bank is greatly altered by hydrothermal solutions. The most obvious alteration is kaolinization, which has affected all the sediments to varying degrees. The shaly matrix of the breccia and conglomerate consists largely of clay, and the less sandy phases of the lake-laid sediments are also kaolinized. Carbonate replacement, also, may be seen in thin sections of the altered sediments, rather large areas of carbonate being scattered through a matrix clay mixed with a subordinate quantity of opal. Most of the carbonate masses are similar in shape to grains of wheat, though some are more angular. In some places the carbonate, which is slightly magnesian calcite, makes up more than half of the rock.

The sediments are thickest in the vicinity of the Empire shaft, having an exposed thickness of 125 feet in the south wall of the Herman and Canal pits. A cross section through the Empire shaft, published by Forstner,[7] indicates a total thickness of about 200 feet. It is in this vicinity that the coarsest breccia, most suggestive of landslide origin, is concentrated. Where the deposits can be seen in the open cuts they thin markedly to the north and east. The thinning is more abrupt to the east, where the contact with the Franciscan rocks rises abruptly, than to the north, where a drill hole driven down from the original surface just west of Sulphur pit shows 60 feet of these sediments. Although the east side is the only part exposed, the writer infers that a north-trending pre-andesite valley, partly filled with landslide material, drained into Clear Lake at a time when the lake stood several scores of feet higher than it does at present. Lacustrine sedimentation and wave erosion affected the edges of the landslide, forming the sandstone lenses and conglomerates. The tule roots found so abundantly in the deposits grew in the littoral zone.

Recent Lava Flow

The Recent sediments at Sulphur Bank are overlain by a Recent lava flow having an average thickness of 100 feet in its central part and covering an area of about one square mile (pl. 21). Where it is fresh the lava is massive, black, and vesicular. The vesicles, which are present throughout the flow, are commonly filled with light-bluish opal and chalcedony, carbonates (including aragonite), and gypsum.

In thin section the rock is seen to contain many large phenocrysts of zoned plagioclase, some othoclase, and a few of augite. The groundmass consists of minute felted plagioclase laths and augite granules embedded in pale-brown glass; the plagioclase laths are oriented in one general direction, showing flow structure. Anderson,[8] who studied a series of thin sections of this rock, found scattered cubes of magnetite and a very few crystals of olivine. He determined that the plagioclase microlites are, in general, calcic andesine and the phenocrysts sodic

[6] Becker, G. F., op. cit. p. 254.
[7] Forstner, Wm., op. cit., fig. 14, p. 62.
[8] Anderson, C. A., op. cit. p. 628.

labradorite. He classed the rock as augite andesite, in which he agreed with Abraham W. Jackson, who studied the rock for Le Conte and Rising in 1882. It is more commonly referred to, however, as basalt, following the usage of Becker. The writer believes that there are three reasons for calling the rock augite andesite: it contains more silica than ordinary basalts, the normative plagioclase is andesine-labradorite, and olivine is almost absent. The following table gives the chemical composition and the norm of the rock:

Table 1—Chemical composition and norm of augite andesite from Sulphur Bank *

Analysis †		*Norm*		*Analysis* †		*Norm*	
SiO_2	56.98	Q	8.90	H_2O+	.76	Ap	.34
Al_2O_3	17.10	Or	8.90	H_2O-	.16		
Fe_2O_3	1.59	Ab	27.77	TiO_2	1.21		
FeO	4.90	An	27.52	CO_2	tr		
MgO	4.43	Di	7.66	P_2O_5	.20		
CaO	7.64	Hy	13.06	S	.01		
Na_2O	3.32	Il	2.28	MnO	.12		
K_2O	1.50	Mt	2.32				
					99.92		

* Analysed by R. B. Ellestad.
† Anderson, C. A., op. cit. p. 628, table 1, opp. p. 640, and pp. 650-651.

Opinions differ also as to the source of the lava. Becker [9] believed that the "basalt of the Sulphur Bank was erupted on the spot" and that "the hot springs (of the area are) * * * of volcanic origin and (are) * * * a later phenomenon than the ejection of the basalt." Le Conte and Rising [10] stated that "the Bank * * * is the lakeward extremity of a lava-stream from one of the nearest volcanoes to the east, toward and almost to which it may be easily traced as a low ridge of lava blocks." Anderson [11] contends that the andesite was erupted from vents now covered by lava. He also believes that secondary vents are represented by small bodies of "agglutinates"[11a] just north of the mines and that there are indications of a vent in the southwestern part of the field. Evidence of the latter consists of a protuberance on the surface of the lava flow, shown by Becker's map, which represents the surface at that place as dipping gently to the east. But the more accurate topographic map used by the writer indicates no such high spot in the southwestern part of the flow's original surface; a low ridge trends eastward through the central part of the flow, just north of the Herman, Sulphur, and Basalt pits, from which that part of the original surface which remains undisturbed slopes gently downward to the west, north, and northeast. Where exposed in the north walls of the pits, the base of the flow dips gently to the west.

The writer believes, with Le Conte and Rising, that the lava flow was extruded mainly from two cinder cones about 1 to 1½ miles east of Sulphur Bank, although the "agglutinate" areas to the north may have been the source of part of the flow.

These "agglutinate" bodies form small rocky mounds, which have a dark brick-red color and are covered with thick brush. They are made

[9] Becker, G. F., op. cit. p. 254.
[10] Le Conte, Joseph, and Rising, W. B., The phenomena of metalliferous vein-formation now in progress at Sulphur Bank, California: Am. Jour. Sci., 3rd ser., vol. 24, pp. 23-33, 1882.
[11] Anderson, C. A., op. cit., pp. 649-651.
[11a] Agglutinate is a term applied by Tyrell in *Volcanoes* (1931) p. 66, to rocks made up of lapilli, blocks, and bombs that were welded together in a semi-plastic state at the time of eruption.

up of vesicular blocks, lapilli, and a small proportion of bombs, which appear to be welded or stuck together in clusters. The blocks and bombs measure several inches across. All this material is so highly oxidized that it would not justify detailed petrographic study.

The cinder cones, which have been little affected by erosion, are described in some detail by Anderson.[12] Their sides are breached by explosive activity, and lava flows extend from the area between them toward Sulphur Bank. These flows are not continuously exposed, and Becker believed that this discontinuity precluded the possibility of this source for the flow at Sulphur Bank, for he did not believe that sufficient erosion had occurred since the Recent volcanic activity to remove so much lava. The lake surface, however, has been lowered several dozens of feet since the Recent volcanic activity, and as a result accelerated erosion has formed gullies floored with well-rounded boulders of volcanic rocks in the area between the cinder cones and Sulphur Bank. Anderson points out, as evidence that the cones are not the source of the andesite, that the lava flow near the cones consists of true basalt, containing numerous crystals of olivine and phenocrysts of labradorite-bytownite; but the petrographic differences between this basalt and the augite andesite at Sulphur Bank are probably no greater than might be expected even in a small flow. Open-pit operations since 1938 have removed so much lava and underlying rock from the Sulphur Bank area that the presence of underlying vents in that area has been disproved.

One reason for regarding the cinder cones as the source is the fact that they stand well above the lava flow, whereas the small agglutinate vents lie as much as 60 feet below the highest parts of the flow. It seems doubtful that 60 feet of erosion has occurred in the lake flats, where the agglutinates crop out. The agglutinate areas may, however, represent secondary vents which are related to the cinder cones and from which lava was extruded about the same time.

Anderson's map [13] shows a well-defined orientation of the agglutinate bodies into two belts of northwesterly trend. One trends N. 45° W. from the area between the cinder cones, and the other trends N. 65° W. from the mined area at Sulphur Bank, passing through Rattlesnake Island, on which there are small bodies of agglutinate not shown by Anderson. The latter belt appears to be on the projection of a fault zone in the Franciscan rocks of the Sulphur Bank pits, described below. The small agglutinate vents northwest of Sulphur Bank appear to be controlled by the same northwest-trending, pre-Recent fault zone that has partly controlled the hydrothermal alteration and ore deposition at the mine.

Post-Andesite Sediments

Unconsolidated lake sands and gravels of Recent age overlap the andesite flow in the inlets and other protected areas along the shores of Clear Lake (see pl. 21). The post-andesite sediments also include two small lenses of clastic breccia containing fragments of sandstone, shale, and andesite. Both extend along the irregular south edge of the flow; one is less than 25 feet, and the other about 75 feet, above the present level of Clear Lake. These sediments were probably deposited in small

[12] Anderson, C. A., op. cit. p. 651.
[13] Anderson, C. A., op. cit. opp. p. 634.

areas, shortly after the extrusion of the andesite flow and at a time when the surface of Clear Lake stood at a higher level.

Structure

The Franciscan rocks exposed in the open pits of the mine are almost everywhere affected by fault movements. The sandstone and shale in the southern and southeastern walls of Herman pit, however, are but little faulted and show moderate folding; their strike varies from place to place in the pit walls but averages about east and their dips are to the south, averaging about 60°. The same general strike persists in the ridge south of the mine, as shown by a few outcrops where the bedding can be observed and by the distribution of float from distinctive beds. A stratum of chert, bordered on the north by hard, massive, green sandstone, can thus be traced along most of the southern edge of the mapped area. The dips observed in the Franciscan rocks underlying the ridge are much gentler than those observed in the pits, but are likewise dominantly southward.

The major structural features of the mine and its vicinity are two groups of faults, the movement on which is mostly pre-Recent and almost wholly confined to the Franciscan rocks.

The more conspicuous group consists of a fault zone which trends about N. 70° E. along the base of the ridge and varies in dip from 50° SE. to nearly vertical. This zone is exposed for 1,150 feet along the axis of Herman pit and in the connecting trench to the east, but is buried northeast and southwest of these openings by the younger sediments and by andesite. The width of the zone ranges from 220 feet in the deepest part of Herman pit to 50 feet in the prospect trench to the east. The zone is made up of numerous reverse faults, marked by strongly sheared gouge and breccia. It is very heterogeneous, being made up of large blocks of sandstone and slices of shale, imbedded in soft shaly gouge and alined parallel to the general trend of the fault zone. Mappable blocks of shale, up to 200 feet long, occur in the northeastern part of the exposures, and sandstone blocks up to 30 feet in length are common everywhere, although shale and shaly gouge are slightly predominant. Scores of closely spaced, curved, anastomosing, irregular shears divide parts of the zone into pillow-like masses, not mappable on the scale employed. The amount of displacement on this fault zone is not known, but is believed to be moderately large.

The second group of faults apparently consists of several fault zones, trending northwestward and dipping nearly vertical. All of these are much less clearly exposed than the prominent fault zone described above. As with the first group, the faulting occurred mainly in the Franciscan rocks, but late movements along pre-existing fractures bent, and in some places cut and displaced, the Recent sediments and the andesite flow.

The only fault of this group that is fully exposed in the Franciscan rocks of the open pits intersects the southern edge of the northeast-trending fault zone near the deep east end of Herman pit. It strikes N. 65° W. across the pit, in the north wall of which it disappears under the Recent sediments and the andesite flow. For 500 feet southeast of the pit it is buried under dumps of waste, beyond which it may be traced, though not continuously, in the Franciscan rocks for a mile. In the

Herman pit, it dips for the most part very steeply to the northeast. It is marked by less than one foot of gouge and breccia in the south wall of the pit, but in the north wall it forms a zone of sheared, brecciated, gouge-like rock 40 feet wide. Relations on the south wall indicate that the northeast side of the fault has been displaced about 50 feet southeastward.

A second fault of this group, exposed 400 feet west of the first in the north wall of Canal pit, strikes N. 45° W. and is vertical. This fault, unlike the first, cuts and offsets the Recent sediments and the andesite flow. The southwest side has moved downward and northwestward, the throw being about 30 feet and the heave 50 feet. It cannot be traced through the clayey sediments to the southeast, or precisely located in the decomposed andesite to the northwest, but its course is marked for at least 1,400 feet in that direction by hydrothermally altered rock.

The third structure of the northwest-trending group is marked on the surface by a monoclinal flexure in the andesite flow, exposed in the north wall of Parrot pit. The strike of this flexure is N. 40° W. and the maximum dip 25° SW. This monocline is believed to reflect post-andesite movement on a covered fault of the northwest-trending group.

The age relation of the two major fault groups is obscured by the fact that recurrent movement has apparently occurred on faults of both groups. In general, the northwest-striking faults appear to be the younger, since one of them offsets the northeast-trending zone in the Herman pit, but shear planes indicating late movement on the northeast-trending zone cut across the northwest-trending fault in that same pit. All of this movement was pre-Recent. If, as was assumed, the post-andesite faults represent renewed movement of older faults, movement has occurred most recently on the northwest-striking set, but the two fault groups may have originated at about the same time.

A prominent joint system in the andesite, parallel to the northwest-trending fault group, is especially well exposed in Parrot pit. The joints trend about N. 50° W. and are vertical.

Hydrothermal Activity and Mineralization

General Statement

Hot aqueous solutions and gases from magmatic sources are rising through the rocks at Sulphur Bank at the present time, and have probably done so continuously since the last volcanic activity in the area. Both during their ascent and afterwards these solutions and gases have greatly altered the rocks. In ascending, they introduced new elements, and at the same time decomposed rock minerals, transporting and redepositing their constituents. Upon nearing the surface, the solutions were oxidized and made acidic, and afterward they probably migrated downward, altering the rocks still further.

Fumaroles and Hot Springs

Numerous hot springs and fumaroles in the fault zones may be seen in the bottoms of the Herman and Canal pits. Solfataric orifices in the rock emit large quantities of gas, which constantly bubbles through the water of all the hot springs observed, giving the erroneous impression that the springs are boiling. Brief observations by the writer indicated that the temperature averages only 43° C. in the springs at the east end

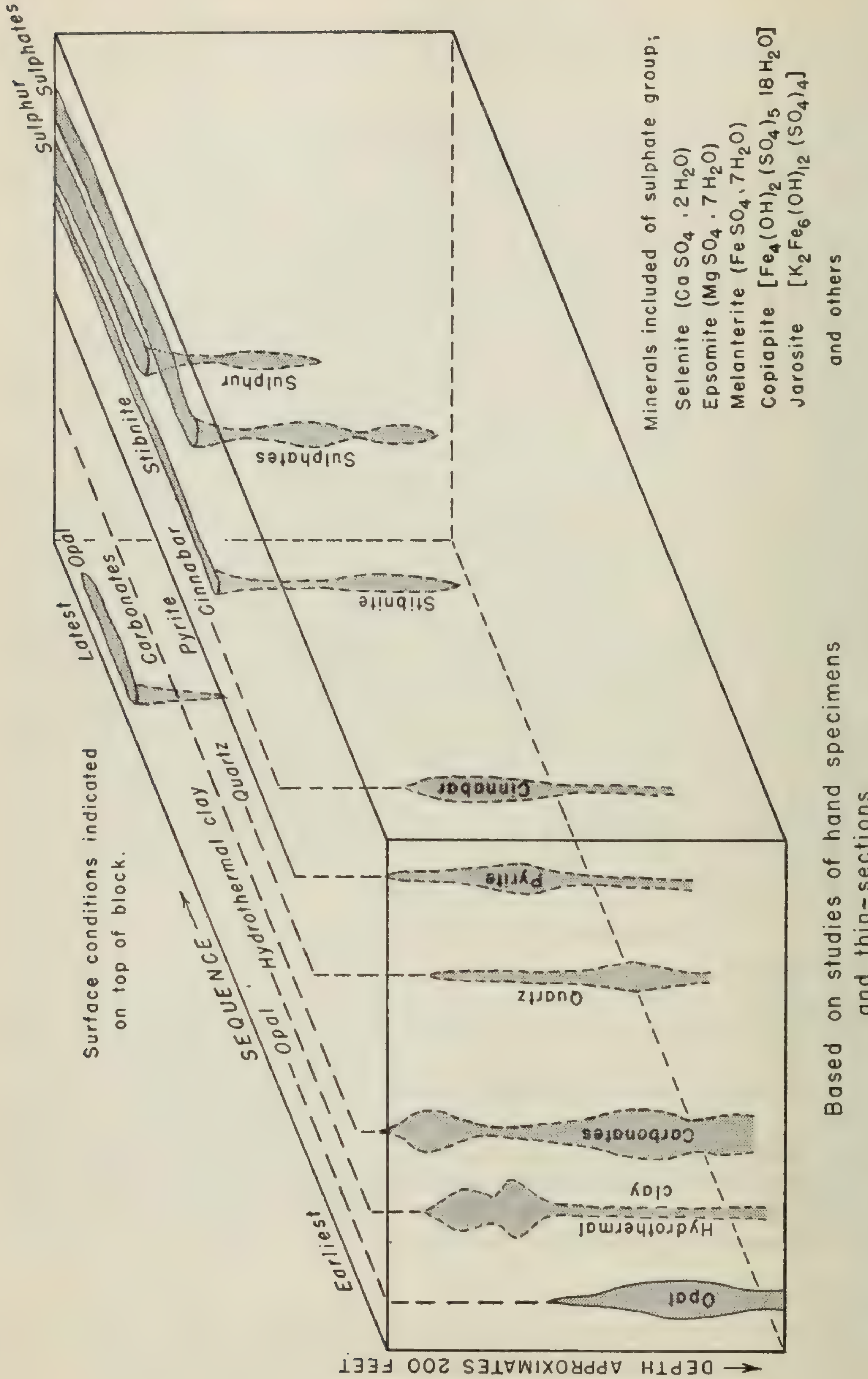

FIG. 3. Diagram showing sequence and depth range of the major hydrothermal minerals at Sulphur Bank. Based on studies of hand specimens and thin sections.

of the Herman pit and 52° C. in those at the west end. Both observations were made in the bottom of the pit, below the level of Clear Lake, so that the inflow of surface water to the pits probably had a marked cooling effect on the original hot ascending waters. Bradley[14] took four temperature measurements in hot springs when the pits were largely in andesite and at a much higher level, and recorded an average of only 36° C. Becker[15] observed temperatures as high as 53° C. in hot-spring waters encountered in the underground workings extending from the old Herman shaft.

The writer did not obtain any gas analyses, but he has no reason to suppose that there has been any substantial change in the composition of the gases since the time of Becker, who gives the following analysis of one sample:[16]

Carbon dioxide, CO_2	89.34
Hydrogen sulfide, H_2S	0.23
Marsh gas, CH_4	7.94
Nitrogen, N	2.49
	100.00

Hydrothermal Minerals

The hot ascending solutions have deposited, and are depositing, a host of minerals in the fractures and on the exposures of the rocks (see fig. 3). Sulfur is commonly precipitated in powdery masses at the orifices of the gas vents and hot springs, and crusts and hair-like fringes of stibnite and hydrous sulfates coat the nearby surfaces; the stibnite occurs but rarely. No complete study of the sulfates found in pits at Sulphur Bank has been attempted. Careful separation and identification will doubtless result in a long list of comparatively rare species. Selenite, the clear glassy form of gypsum, is by far the commonest of the sulfates. Copiapite, the citron to sulfur-yellow hydrous sulfate of iron, is likewise common. Epsomite, jarosite, and melanterite, and possibly alunogen, are somewhat less so, the jarosite being largely confined to fault zones within the Franciscan rocks. Late crystalline pyrite and a little marcasite are associated with the sulphates.

Cinnabar forms finely crystalline coatings in fractures and on blocks of sandstone of the Franciscan group in fault breccia. In places it completely coats the surfaces of fault blocks up to 6 feet in length, but these thin coatings do not make high-grade ore. The richest ore in the mine consists of fault gouge through which cinnabar is disseminated as "fines." Fine-grained cinnabar has been deposited in veinlets and dendrites throughout the kaolinized Recent clastic sediments, and in altered andesite adjacent to joints and sheeting planes.

No direct evidence has been observed by the writer to indicate that cinnabar is being deposited at Sulphur Bank at the present time. All the cinnabar seen in the mine, with the exception described below, appears to be older than the modern sulphate minerals. The solutions which deposited the cinnabar doubtless rose along the same channels as the hot waters issuing today, but unadulterated by surface waters their composition may have been materially different. If any mercury is con-

[14] Bradley, W. W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 67, 1918.
[15] Becker, G. F., op. cit., pp. 259-60.
[16] Becker, G. F., op. cit., p. 258.

tained in the hot waters ascending at present, it is perhaps deposited as mercuric sulfide at depths greater than those explored by the mine.

Minute veinlets of cinnabar, thought by the writer to be of secondary origin, fill interstices in coarse material at the base of the dump on the south rim of the Herman pit. These veinlets are wholly confined to the dump, which is at some distance from the ore bodies in the mine, and no cinnabar is found in the bedded sandstone of the Franciscan group underlying the dump. The cinnabar in these veinlets is probably from cinnabar-bearing andesite in the dump.

Alteration of the Rocks

The augite andesite in the mine area is leached for 15 to 25 feet below the surface to dazzling white, powdery silica which is largely opal. This silica is highly porous, and is saturated in places with late sulfates and crystalline sulfur. It was in such material, in the vicinity of Sulphur Pit, that the early sulfur-mining operations were begun. Le Conte and Rising [17] were the first to indicate the chemical reactions involved in the formation of the leached, sulfur-bearing zone. They showed that rising waters carrying abundant H_2S would yield H_2SO_4 at the surface, where oxygen was plentiful: $H_2S + 2O_2 \rightarrow H_2SO_4$. The sulfuric acid thus formed decomposed all the minerals of the andesite, leaving only powdery opal, and the acid solutions deposited hydrous sulfates in the open spaces of the leached rock. Just below the surface, where oxygen is scarcer, the product is sulfur: $2H_2S + O_2 \rightarrow 2H_2O + 2S$.

Below the leached zone, the andesite along joints and sheeting planes is widely altered to clay. This alteration, probably accomplished largely by ascending hot solutions, produced white to gray clay, which encloses rounded boulders of fresh andesite as much as 6 feet in diameter. Associated with the clay are large quantities of hydrous sulfates and, in places, of sulfides. Glassy opal is mixed with the clay near the bottom of the leached zone, and in many places it extends down into the bouldery zone for several feet. Where the opal and the clay occur together, some of the opal appears to have been formed before the clay. Powdery goethite is commonly mixed with the opal. Cinnabar and pyrite form stringers and seams throughout the clay between the boulders. Partial replacement by opal and alteration to clay have occurred near the borders of the fresh boulders, where the original texture of the andesite is preserved. Thin sections of rock thus altered show partial to complete kaolinization of the feldspar crystals and replacement of other parts of the rock by opal. The sulfides have been introduced farther from the boulders near the joints, where the original texture of the rock has been obliterated. Thin sections from the sulphide-bearing material show large veins and blobs of pyrite and cinnabar deposited in roughly concentric fractures and in the spaces between masses of completely kaolinized feldspar. The sulfide masses have kernels of pyrite, surrounded by fringes of cinnabar.

As already indicated, the Recent sediments beneath the andesite are even more extensively kaolinized than the andesite itself. In structurally favorable places, cinnabar and pyrite are associated with the clay formed in the sediments, and the surfaces of altered rock are coated with late acicular stibnite and with various sulfates.

[17] Le Conte and Rising, op. cit., p. 33.

Hydrothermal alteration is also evident in the Franciscan rocks along the fault zones. In these rocks, carbonatization by replacement and veining occurred first, and fractures were later filled with pyrite and cinnabar.

Localization of Hydrothermal Activity

The hot springs and fumaroles at Sulphur Bank are scattered along the northeast-trending fault zone explored by the Herman and Canal pits. Solfataric activity is greater near the intersection of that zone with the easternmost of the northwest-striking faults, in the deep east end of Herman pit. A second area of such activity lies at the west end of Herman pit, where the second northwest-striking fault intersects the main fault zone. It is there that two artificial geysers were created by churn drilling in the autumn of 1944. The varied hydrothermal alterations and precipitations described above are all loosely controlled by the same structural features. Alteration has occurred along all the faults and fault zones described above, but has been most intense at the intersections of the northeast-trending fault zone with the northwest-trending faults, especially the easternmost.

Alteration is not confined to the rocks cut by the faults; where undisturbed younger rocks overlie the faults, they are altered above the faults and especially above the fault intersections. Zones of relatively intense kaolinization in the andesite are consequently thought to reflect faults in the Franciscan rocks underneath (pl. 21). The most prominent of these zones trends northwestward from the west end of Herman pit to the Northwest pit, and a less prominent one trends northwestward through Wagon Spring pit. In both these zones concentrations of cinnabar, rich enough to make ore in many places, are associated with clay between boulders of andesite. A third quicksilver-bearing zone, in which there has been replacement by opal but no kaolinization except locally, trends northwestward from the south wall of the Parrot pit to the Basalt pit, along the monoclinal flexure previously described, and shown on plate 21. Where this zone crosses the projection of the main northeast-trending fault zone there is an area in which the andesite is more intensely kaolinized than at any other place at Sulphur Bank, being completely altered to clay. This locality is the only one where the andesite still overlies the northeast-trending fault zones; everywhere else the andesite above the fault zone had been mined before the writer began his field work. Earlier publications, however, indicate that the southern edge of the flow was highly kaolinized and carried considerable cinnabar.

Kaolinization of the Recent sediments is likewise most intense above the projection of the northeast-trending fault zone, especially where it is intersected by northwest-striking faults. Sulfide mineralization in the clays is concentrated near the fault intersections and the contact between the sediments and the overlying andesite flow.

In the Franciscan rocks, carbonatization is apparently uniform throughout the fault zone, and sulfide mineralization is widespread in the fault breccia, but only near the fault intersections is cinnabar sufficiently concentrated to make ore.

Ore Bodies

As already indicated, the major ore bodies at the Sulphur Bank mine are mostly at the intersections of the major fault zones, and smaller

*Table 2—Ore Mined 1937-1942 by localities**

Location by pits	1937		1938		1939		1940		1941		1942	
	Tonnage	Lbs. Ton	Tonnage	Lbs. Ton	Tonnage	Lbs. Ton	Tonnage	Lbs. Ton	Tonnage	Lbs. Ton	Tonnage	Lbs. Ton
A-4	377	7.17	866	18.4	2,052	16.8	----	----	----	----	----	----
Basalt	----	----	4,921	13.9	7,329	10.3	2,626	11.4	1,651	14.0	364	4.5
Canal	2,138	12.4	----	----	462	8.6	2,246	18.4	7,682	34.5	352	8.2
Herman	1,033	5.69	4,086	15.3	6,470	12.6	11,197	19.6	2,655	9.4	13,706	18.8
Parrot	12,977	17.38	5,664	15.2	611	15.7	----	----	----	----	----	----
Wagon Spring	----	----	2,693	8.6	367	7.3	246	1.9	2,355	6.7	5,177	10.0
Others	5,484	6.2	536	----	520	4.8	2,806	12.2	5,904	----	2,587	10.7
Totals	22,009	Average= 13.13	18,766	Average= 13.2	17,811	Average= 11.74	19,121	Average= 16.4	20,247	Average = 20.0	22,186	Average= 14.8

* Published by permission of Bradley Mining Co. (Worthen Bradley).

deposits occur in the fault zones away from observed intersections. The shapes and sizes of the ore bodies also depend, however, upon the character of the rock in which they occur. In general, the ore bodies in the Franciscan rocks are steep and chimney-like, following the pitch of the fault intersections. The deposits in the Recent sediments are generally concentrated near the contact of those sediments with the lava flow, where they spread out, mushroom-like. The ore deposits in the andesite are more widely dispersed, and are only loosely confined to zones of alteration that have indefinite boundaries. The ore occurs along joints and sheeting planes, where it forms stringers in clay that enclose large boulders of fresh andesite. Rich pockets of high-grade ore are concentrated at the intersections of these fractures and must be mined selectively.

By far the largest ore body mined at Sulphur Bank is in the east end of the Herman pit, at the intersection of the two major fault zones. The ore in the andesite, the sediments, and the Franciscan rocks has there been removed to a depth of more than 150 feet (see table 2), but ore was exposed in the bottom of the pit in July 1943, and every indication points to the downward extension of a steep southeast-pitching ore shoot, measuring about 20,000 square feet in horizontal section and averaging about 5 pounds of quicksilver to the ton.

A second area of mineralization, containing discontinuous but rich ore bodies, lies at the intersection of the middle northwest-striking fault with the main fault zone, along which it extends for some distance southwest of the intersection. This area has been explored in the west end of Herman pit and the eastern part of Canal pit. The richest ore bodies mined from open pits in this area were in the andesite and in the upper few feet of the Recent sediments, but according to Forstner,[18] three early shafts, the Diamond, Babcock and Empire shafts had developed a large ore body in the Franciscan rocks near their contact with the Recent sediments. This body extends along the southern border of the northeast-trending fault zone; its southwest end is 400 feet, and the northwest end nearly 100 feet, from the projected intersection. It is 40 feet wide and 40 to 120 feet deep, being deepest at the intersection. According to Forstner's map and section, the top of this ore body is 1280 feet above sea level at its northeast end and 1250 feet at its southwest end. In 1943, the bottom of the open pit was 1230 feet above sea level at the northeast end of this ore body and about 1275 at its southwest end. Forstner's account has been partly confirmed, in that ore containing as much as 20 pounds of mercury to the ton was mined in the open pits from what could well be the top part of this ore body's northeast end. As the underground workings in this area are said to have been abandoned before much of the ore in this body was mined, it seems likely that additional ore will be revealed by further development in open pits. Churn drilling conducted by the company late in 1944 indicated ore of sufficiently high value to justify them in deepening the open pits in this part of the mine.

A third ore body that has been a consistent producer since the early days has been opened up in the Wagon Spring pit, about 500 feet north of the Herman pit. It lies wholly in andesite, being of the inter-boulder type, and consists of high-grade stringers scattered over an area of

[18] Forstner, William, op. cit. fig. 14, opp. p. 62.

nearly 90,000 square feet. Ore mined in this area from 1938 to 1943 carried from 2 to 10 pounds of quicksilver to the ton, averaging about 7. There is no reason to believe that this ore does not persist downward to the base of the andesite.

Another highly productive area, also in andesite, extends along the northwest-trending fault and flexure that pass through the Parrot and Basalt pits. Native quicksilver was said by A. F. Wolbert, mine superintendent, to have been found in both pits. This area produced over 36,000 tons of some of the mine's highest-grade ore in the years 1936 to 1942 (see fig. 5), but since then no new ore has been discovered in this part of the mine.

Colors of cinnabar are observed in nearly all the areas worked by open pits. A discontinuous zone of such colors follows a zone of rock altered to clay and mineralized with sulfates which marks the northwestward extension of the middle and eastern cross-faults. From the strike of the faults, as exposed in the Herman and Canal pits, it seems probable that they converge to the northwest and merge into a single fault zone. The cinnabar observed in this zone is not abundant enough to make ore that could be profitably mined at the present time, but extensive open-pit mining was carried on in the zone by the Bradley Mining Company in developing the Northwest pit during their early years of operation.

Ore bodies in andesite, exposed in Wagon Spring pit, in the Basalt pit, and in the area directly north of the Canal pit, define a zone that lies parallel to the main northeast-trending fault zone and about 500 feet northwest of it. The ore bodies may mark the intersections of an underlying fault, trending northeast, with the northwest-trending faults of the mine, and they appear to be worth prospecting.

THE MINE

Underground Workings

Although no underground mining has been attempted at Sulphur Bank for several years, at least four shafts sunk by the early operators were important sources of production. The deepest of these was the Herman shaft, which was probably begun in 1875 (see pl. 21). In the summer of 1882 it was down to a depth of 310 feet, and five short levels had been driven northwestward from it, at depths of 104 feet, 157 feet, 210 feet, and 260 feet and at the bottom. The most extensive was the 210-foot level, which had a total length of 232 feet. This level passed through 70 to 80 feet of barren rock northwest of the shaft, then cut the ore body that was afterward mined from the Herman pit, and extended well into barren rock northwest of the ore body. The 260-foot level penetrated the ore body for a total distance of 136 feet. By the time Becker studied the property, late in 1887, the Herman shaft had been sunk to its final depth of 417 feet (about 950 feet above sea level), and two more levels had been added, making a total of seven. An air shaft had also been sunk to the northwest end of the 210-foot level and extended 10 feet below the level. All the workings that stem from the Herman shaft explored the large southeast-dipping ore body at the east end of the Herman pit.

Between 1888 and 1897 the Diamond and Babcock shafts (see pl. 21) were sunk to explore the ore body exposed in the west end of the Herman

pit and the eastern part of the Canal pit. The Babcock shaft was 140 feet deep, bottoming about 1210 feet above sea level. The Diamond shaft was 200 feet deep, bottoming about 1140 feet above sea level. Two levels were driven from it into the ore shoot to the south, one, about 100 feet long, at 110 feet, and the other, about 80 feet long, at 186 feet.

By 1902 the Herman, Diamond, and Babcock shafts were caved, but in that year the Empire shaft was being sunk, with the idea of driving drifts northward to tap ore bodies that supposedly underlay producing surface pits, and several small winzes were sunk, also, in the bottoms of surface cuts. The Empire shaft reached a depth of 240 feet, bottoming about 1,110 feet above sea level, and northwest of it the Parrott shaft was sunk 150 feet (1,230 feet above sea level). Mounting difficulties in mining, together with financial reverses, brought about the closing of the Empire shaft workings in 1906, even though a partially developed ore body was then still exposed, and no extensive underground mining has been carried on since then. The Bradley Mining Company sank the Basalt shaft (see pl. 21), about 100 or 150 feet deep, and drove one small drift, but found no ore. The shaft was abandoned because of hot waters and gases. A small tonnage of rather high-grade ore was also reported by the Bradley Mining Company as having been mined from the A-4 shaft, southeast of Parrott pit.

At the time of field work, and to the middle of 1945, all underground workings of the Sulphur Bank mine were caved and inaccessible.

Open Pits

It is difficult to trace the development of open-pit mining at the Sulphur Bank satisfactorily from available literature. The original sulfur workings were apparently in the vicinity of the present-day Sulphur pit, and from there shallow cuts were dug farther and farther southeastward to the vicinity of Wagon Spring cut and the broad bench to the east, just north of Herman pit (see pl. 22). At the time of Le Conte and Rising's investigations these open pits, all near the southern border of the andesite flow, were being actively mined and were producing high-grade ore. Becker, in 1888, described the surface cuts as a "labyrinth of excavations," without going into detail. By 1908 the highly productive Western cut had been developed in the altered andesite that then lay directly above the spot now occupied by the three-way road junction at the east end of Canal pit. The Apex cut, directly southwest of Sulphur pit, several small cuts in the Parrott pit area, and the Chimney cut, the predecessor of the Northwest pit, had also been developed.

Surface mining during World War I further developed existing cuts, but it was not until 1927, when the Bradley Mining Company's operations began, that large tonnages of rock and ore were removed from the open pits, giving Sulphur Bank a wholly new aspect.

At the time of Ransome and Kellogg's [19] and Ross's [20] visits in 1938, activity was greatest at the Parrott pit, which was the deepest part of the surface mine, its bottom being 1,300 feet above sea level. Since then the mining has shifted to the east, and the large Herman pit has been deepened by 130 feet. The Surphur Bank mine now (1945) consists of seven connected open pits, covering a total area of 1,570,000 square feet.

[19] Ransome, A. L., and Kellogg, J. L., Quicksilver resources of California: California Jour. Mines and Geology, vol. 35, no. 4, p. 397, 1939.

[20] Ross, C. P., Quicksilver deposits of the Mayacmas and Sulphur Bank districts, California: U. S. Geol. Survey Bull. 922-L, pl. 50, (map in pocket) 1940.

The three deepest lie along the northeast-trending fault zone at the base of the ridge. The floors rise, in general, westward, being 1,200 feet above sea level at the eastern end of the Herman pit, somewhat higher in the Canal pit, and 1,290 feet above sea level in the Parrott pit. The sides of the pits are cut into benches 20 feet wide alternating with 15-foot vertical walls, except where slides have evened the profile. Two ramp roads, with cut-offs to the benches, lead into the pits from the original surface, which is 1,400 feet above sea level at the east end of the mine and 1,340 feet at the west end. A second series of three pits lies directly north of the three mentioned above, at a considerably higher altitude. The bottom of Wagon Spring pit, at the east, is 1,340 feet above sea level, that of Sulphur pit, in the center, 1,370 feet, and that of Basalt pit, at the west, 1,320 feet. Northwest pit, which lies 300 feet north of Basalt pit and bottoms at an elevation of 1,355 feet, is connected with the Sulphur pit area by the narrow Chimney cut. All the northern pits are served by a network of roads on the north and west sides of the property.

Ore and waste rock are dug from the pits by three Bucyrus-Erie power shovels, after blasting of the harder rock with dynamite. The shovels are of ¾-yard, 1½-yard, and 2-yard capacities, and load into Diesel-powered dump trucks. The Bradley Company, in their early operations, had the ore hand sorted on the trucks as it was being loaded, but in recent years the ore and waste rock have been separated entirely by the shovel operators. The waste rock is trucked to two huge dumps on the west and northeast sides of the open-pit area, and the ore is taken over half a mile of road to the plant, a third of a mile distant to the southwest.

Plant

The plant at Sulphur Bank has been described by Ransome and Kellogg [21] as follows:

"Ore from the mine is dumped through a grizzly into a primary ore bin. A 10 by 20-in. Blake jaw crusher breaks the oversize rock to about 2-in. size. It is then transported by a series of conveyor belts to a hopper at the upper end of a 5 by 60 ft. rotary furnace. As the ore drops from the conveyor belt to the hopper, the stream is cut at 5-minute intervals by an automatic device which diverts the flow into a sample box. Feed to the kiln is purely by gravity methods, and back spilling is prevented by a set of 6 helical blades 2 ft. long, arranged inside the furnace to carry the ore away from the feed end.

"The firing of the furnace at Sulphur Bank is unique in modern metallurgical practice. Because of the high sulphur content in the ore treated, it was found that in order to get complete combustion of sulphur, the firing must be done at the feed end of the furnace. With good temperature control no unburned sulphur vapors now enter the stream; and, consequently, there is no recombination of mercury and sulphur in the condensing system. Fuel oil used for firing is a 19-gravity oil, and the consumption for the year 1937 averaged 12.95 gal. per wet ton of ore treated. The rotary furnace, when first built, had diameter of 5 ft. and was only 40 ft. long. Later a 20-ft. section was added, with a view to increasing the tonnage. The capacity, however, was not increased despite the fact that the furnace became more efficient at burning out the sulphur. It is set at a slope of half an inch to the linear foot, and rotates about 1½ to 2 r.p.m. The method of disposal of calcined ore is quite interesting. From the lower end of the furnace it is sluiced by a continual flow of water in a trough to a drag line. It is then scraped to the end of a long dump by a V-shaped scraper.

"Gases leave the furnace and enter a Sirocco dust collector at a temperature of 1,155° F. (625° C.), and because of this exceptional heat, a very large and complicated condensing system is required. The primary unit consists of three parallel rows of mild-steel vertical pipes, 10 in. in diameter and 26 ft. high, with 6 pipes per row. This is followed by 5 parallel rows of steel vertical pipes, 10 in. in diameter

[21] Ransome, A. L., and Kellogg, J. L., op. cit., pp. 398-399.

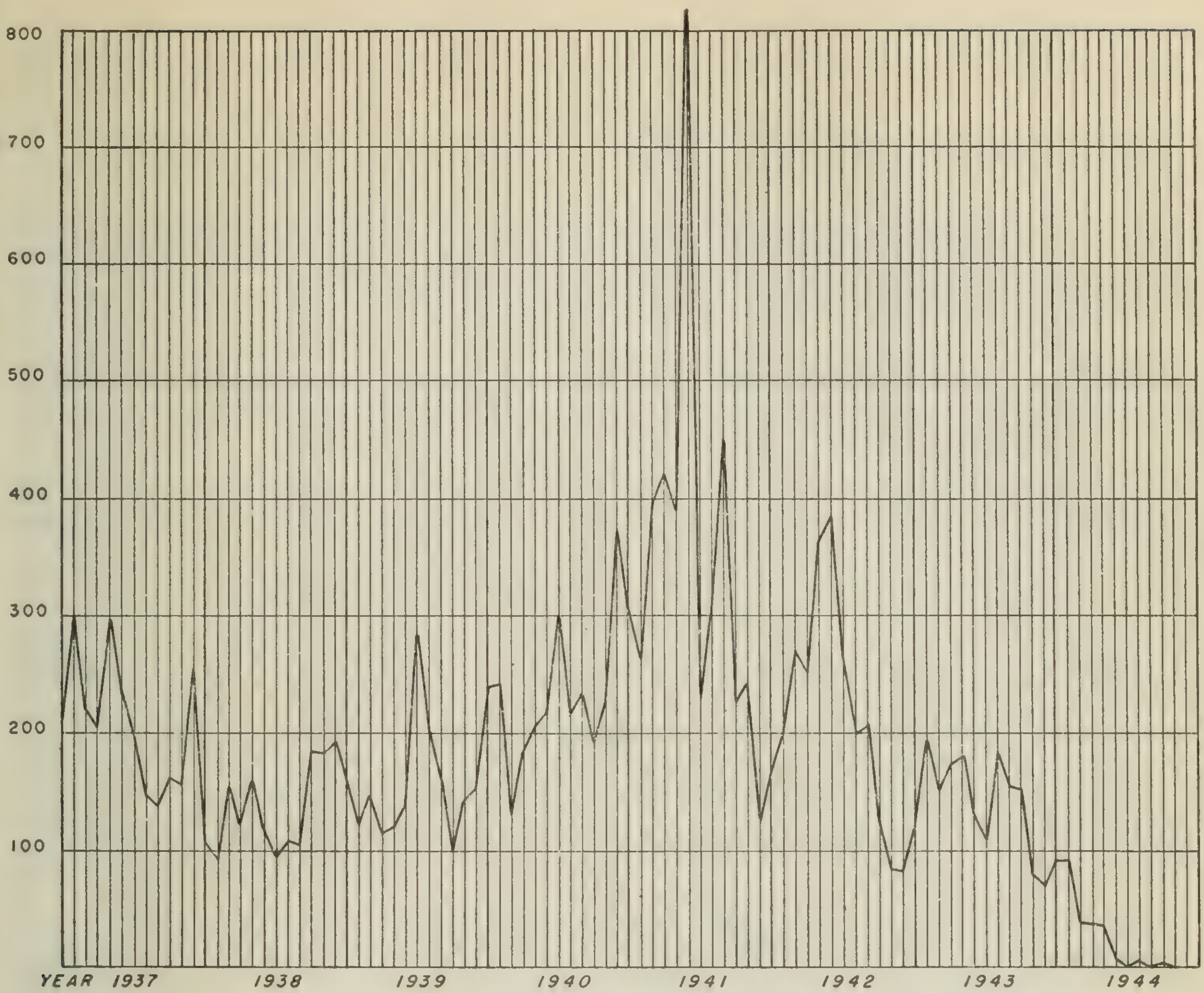

FIG. 4. Graph showing monthly production in flasks, January 1937 to October 1944, Sulphur Bank mine, Lake County.

and 9 ft. high, with 5 pipes per row; and 5 parallel rows of vertical tile pipes, 10 in. in diameter and 9 ft. high, with 12 pipes per row. This gives a total of 103 pipes. The unit was designed by C. N. Schuette, and is similar to the one used at the Great Western mine. The vertical pipes join inclined tile outlets at the base, which deliver mercury and soot to wooden pails and boxes. The gases pass from the primary unit into a secondary unit, which is the one described by Worthen Bradley in U. S. Bureau of Mines Information Circular 6429.* This unit consists of a series of wooden tanks and spray towers, washed by a continuous flow of water, which gives a low-grade mud recovery. At the end of the system is a 48 in. wooden stock, 40 ft. in length.

"The low-grade mud from the secondary unit is sent to two thickeners. The partially dewatered product is pumped to an agitator, whence it is sent to a 2-cell flotation unit. The concentrates are filtered, dried, and retorted in one double, oil-fired D retort. Soot and mercury which are collected from the primary system are mechanically agitated with unslaked lime, and the remaining mud joins the flotation concentrates in the retorts."

Economics of the Mining Operations

A wealth of data on the economics of mining quicksilver ore at Sulphur Bank by open-pit methods have been carefully accumulated by the Bradley Mining Company. Mr. Worthen Bradley, president of the company, has generously made all these data available to the writer, who has prepared from them a series of five graphs for the years 1937-1944. This period includes the rise and decline of the boom brought

* Bradley, Worthen, Method and cost of recovering quicksilver from low grade ore at the reduction plant of the Sulphur Bank Syndicate: U. S. Bur. Mines Information Circular 6429, pp. 7-8, 1931.

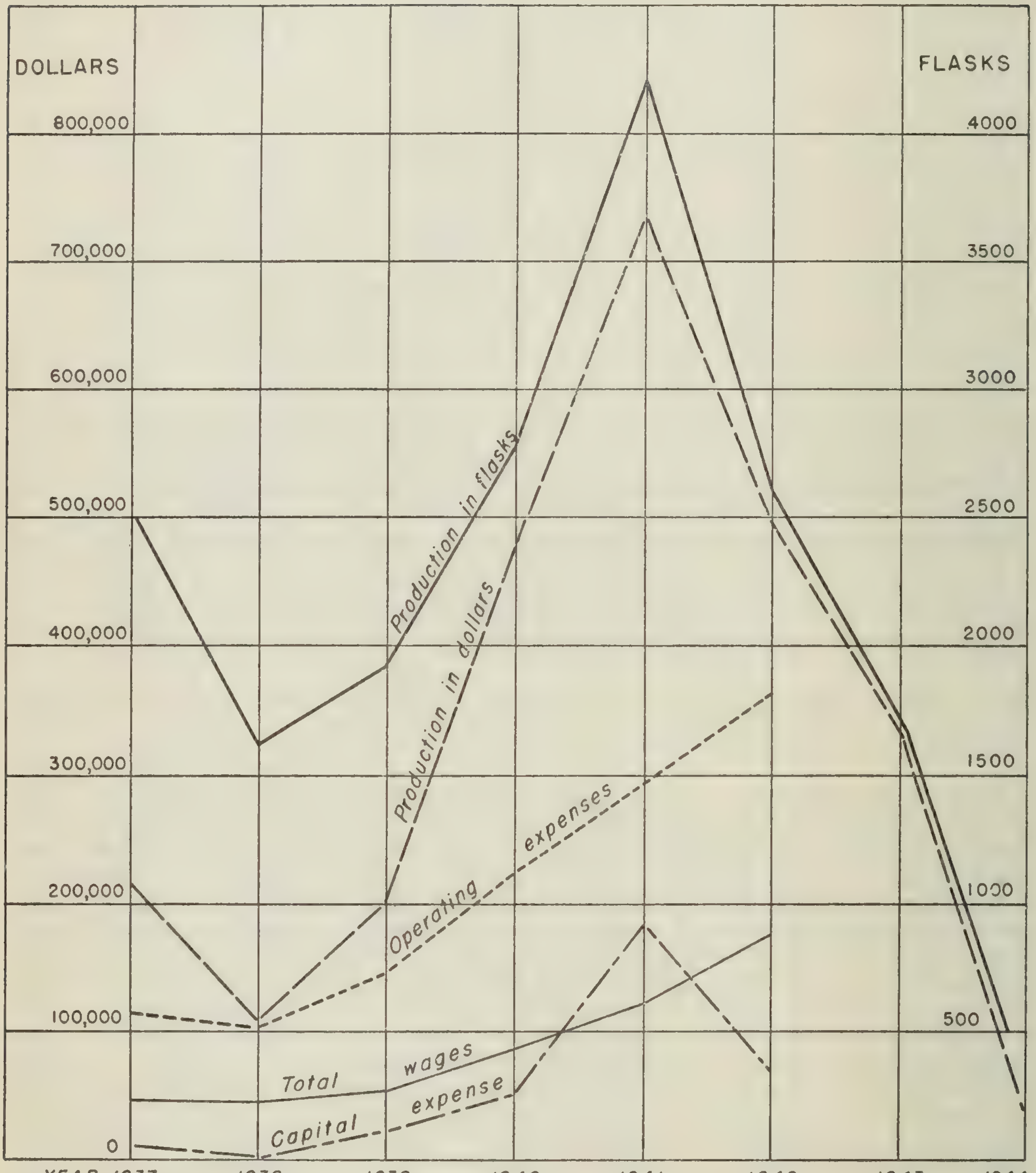

FIG. 5. Graph showing production and expenses, 1937-1944, Sulphur Bank mine, Lake County.

about at this mine by World War II, and a study of the costs in relation to tonnages removed and to quicksilver prices helps considerably in predicting the future of mining at Sulphur Bank.

Graph I (fig. 4), showing the monthly production from January 1937 to November 1944, brings out the fact that production from open pits reached a peak in the summer of each year, when dry weather offered favorable conditions. The high production attained in the summer of 1941 is strikingly shown, as is the rapid decline following the autumn of 1943.

Graph II (fig. 5) shows production, both in flasks and in monetary value for 1937-1944, inclusive, and expenses for 1937 to 1942; figures for expenses in 1943 and 1944 are not available. Both production curves show a marked peak in 1941, followed by a rapid decline to the present time. Up to the beginning of 1943, the curve for monetary value becomes progressively closer to the curve for production by flasks, reflecting the steady rise in price, but after that they diverge a little, reflecting a drop in price. Operating expenses, in so far as they are recorded, rise continuously at an increasing rate, reflecting an increase in total wages. Capital expenses also rise in general, but they reach a peak in the boom year of 1941, which is the only year in which they are above the total wages. The graph indicated that in 1943 expenses would begin to exceed the value of the mercury produced, and this indication was later verified.

Graph III (fig. 6), showing tonnage of rock moved from the open pits in the period 1937-1942 and cost of mining for the same period, is perhaps the most striking of those prepared. The rock moved is broken down into waste and ore. The total rock moved is shown to contain a high percentage of waste rock, which increases sharply from 1938 on. The curves representing total rock and waste rock rise logarithmically, at a rapidly increasing rate, and so does the cost-of-mining curve, though a little less sharply. Tonnage of ore, on the other hand, remains essentially constant, at a comparatively low level, throughout the period. It is interesting to note the relation between the curves of Graph III and the sources of the ore. Prior to the beginning of 1940, when tonnage of waste and cost of mining began to rise very abruptly, all the ore came from scattered high-grade seams in the extensive ore bodies in andesite. Since then the ore has come increasingly from the narrower steeply-pitching ore shoots in the Franciscan rocks, and the amount of waste rock that must be moved from the deepening pits to gain access to the dwindling horizontal sections of ore has consequently risen at an unprecedented rate. The deeper the ore lies in the pits, moreover, the more expensive it is to mine, so that mining costs increase more rapidly each year.

Graph IV (fig. 7) shows the rise and fall of the price of quicksilver throughout the period, together with total costs, costs of mining, and costs of plant operation to the end of 1942. The recorded total costs rise steadily and rapidly, whereas the costs of mining rise slowly to 1941, and then leap suddenly upward. Plant operation costs are relatively constant. The graph indicates that war-time rises in labor costs, taxes, etc., coupled with the rise of mining costs due to deepening of the pits and change in the nature of the ore bodies, demand a price of at least $200 per flask for continued successful operation.

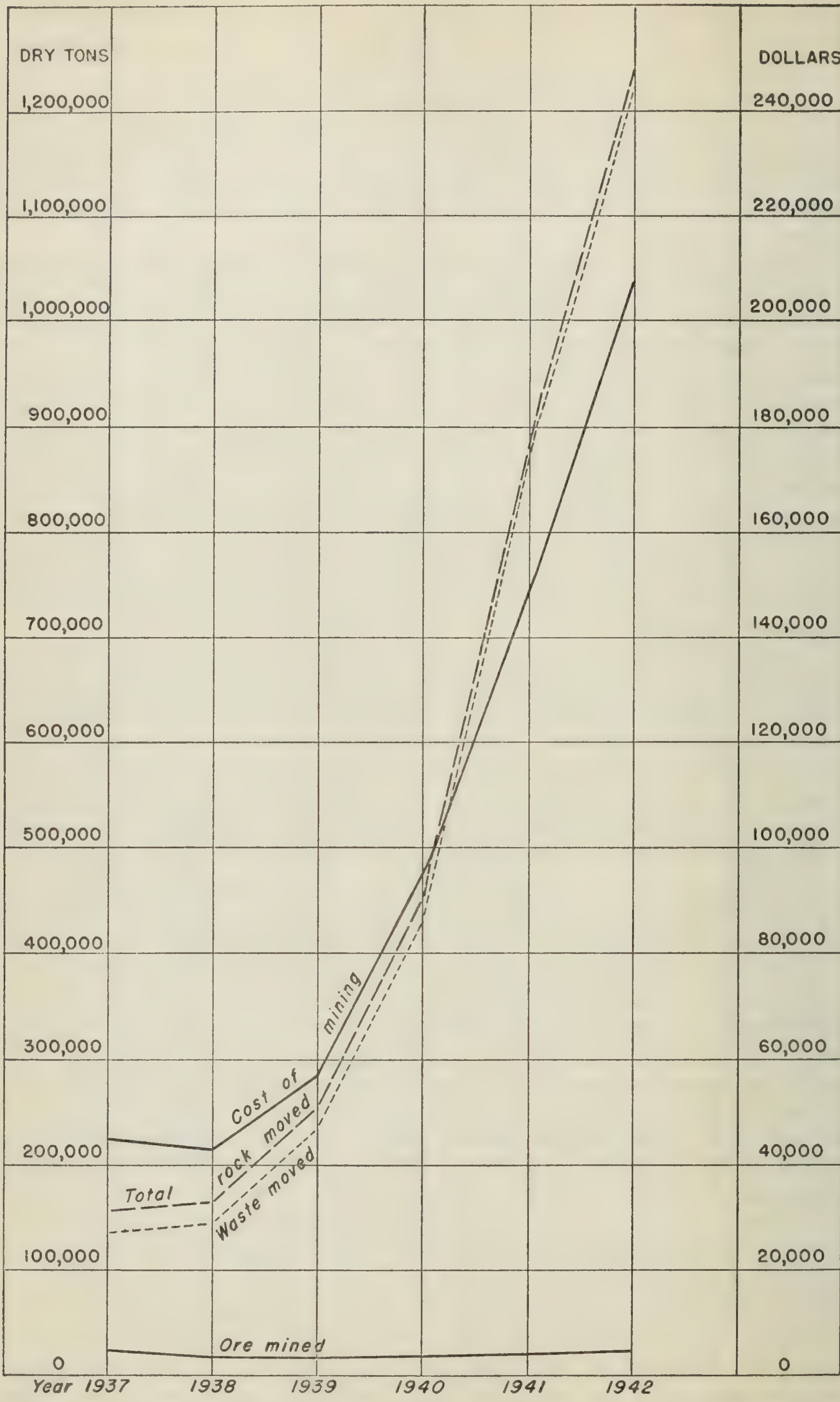

FIG. 6. Graph showing rock moved from pits and cost of mining, 1937-1942, Sulphur Bank mine, Lake County.

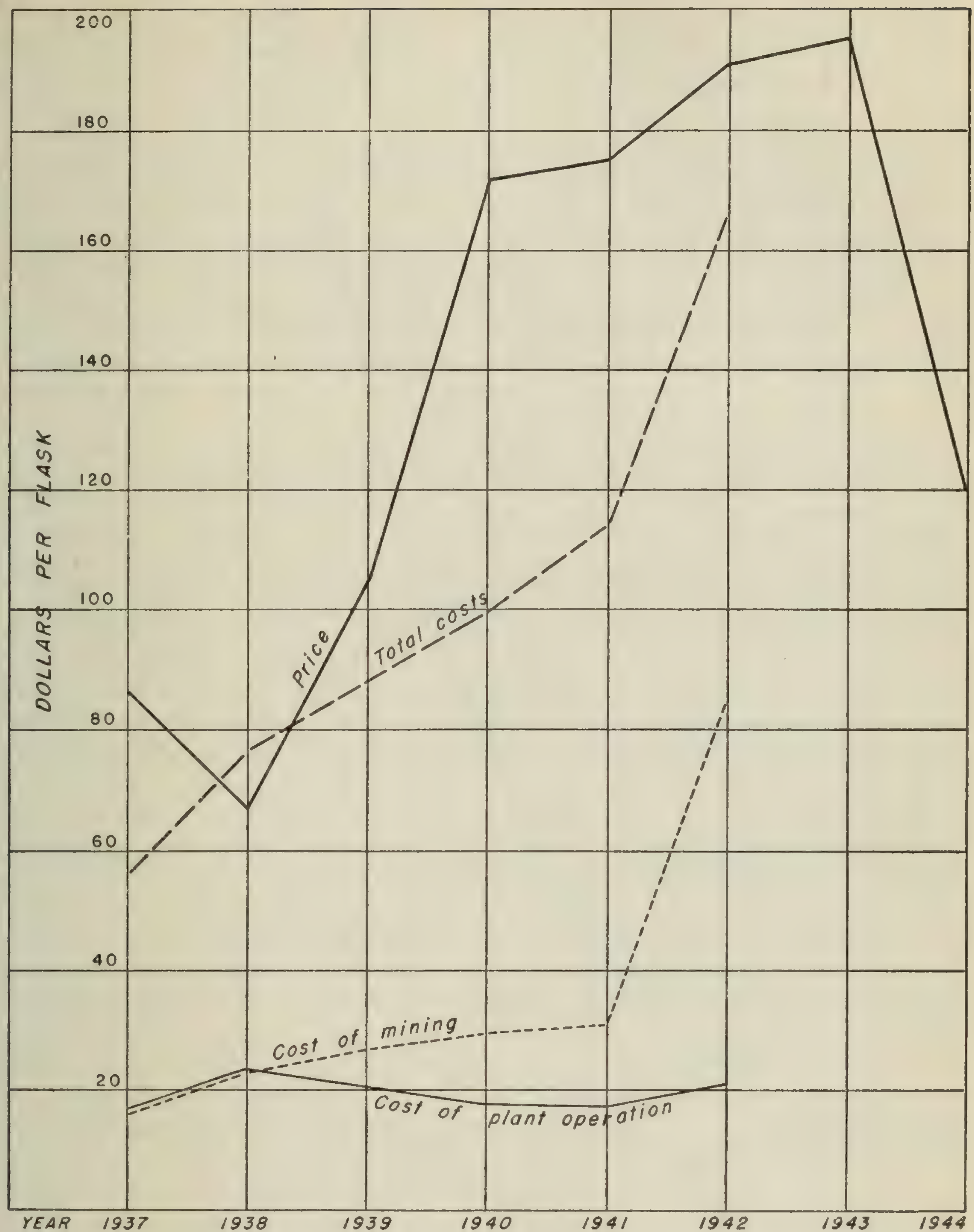

FIG. 7. Graph showing costs and price per flask, 1937-1944, Sulphur Bank mine, Lake County.

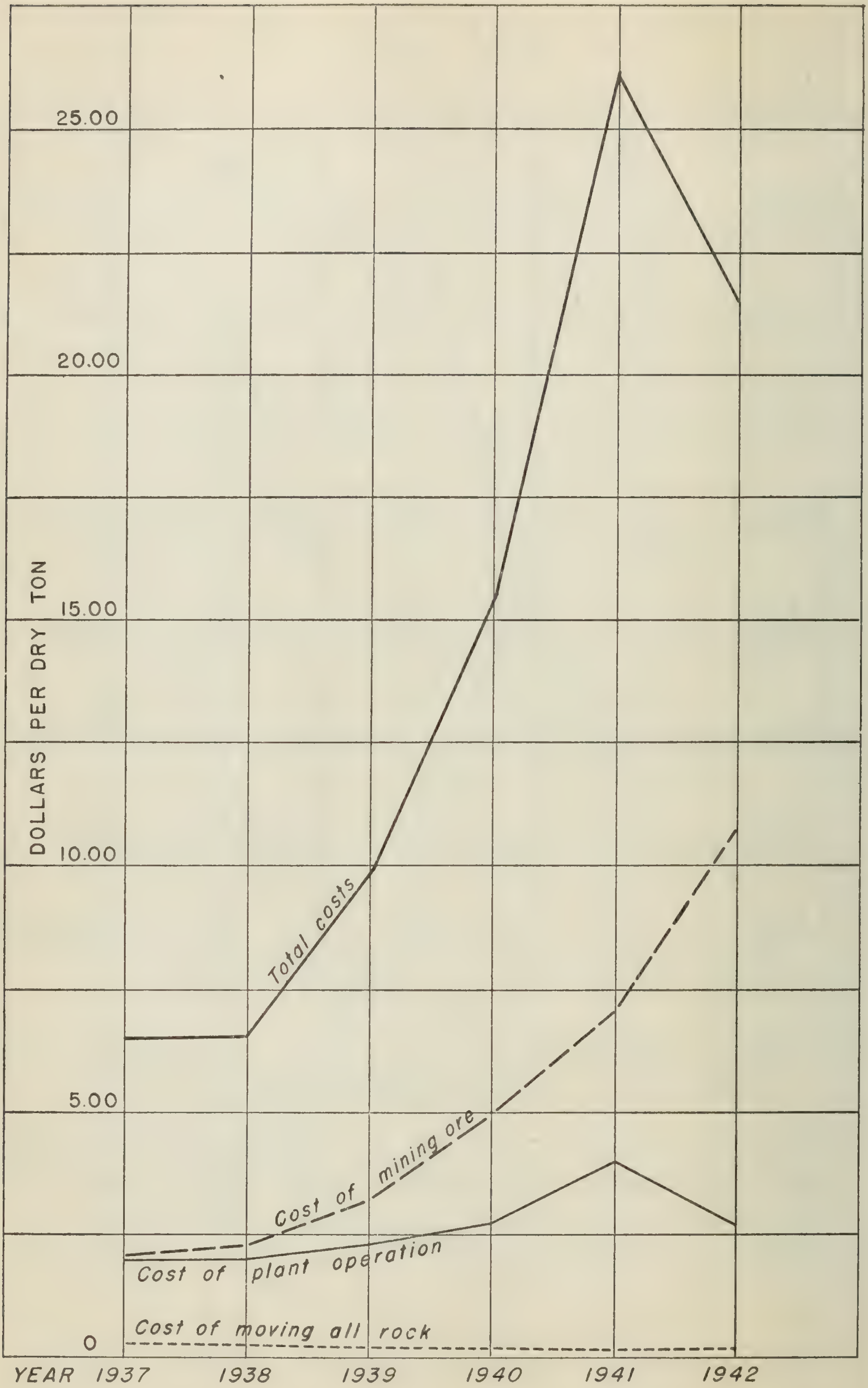

FIG. 8. Graph showing costs per dry ton of ore, 1937-1942, Sulphur Bank mine, Lake County.

Graph V (fig. 8) gives some costs per dry ton of ore up to the end of 1942. Again the total costs rise rapidly to the beginning of 1941, but drop off in 1942. The costs for mining ore rise at an increasing rate during this period, whereas the costs for moving all rock and for plant operation remain relatively constant and low. This graph again brings out the increase in cost of removing the ore, an increase due partly to natural causes and partly to the general rise in costs brought about by the war.

The economic data for these eight years thus indicate a gloomy future for Sulphur Bank. Most of the cheaply mined ore of the andesite flow has been extracted, and open-pit methods seem ill adapted to mining the steeply pitching, pipe-like ore bodies in the fault zones of the Franciscan rocks. Since underground mining is very difficult and costly because of its effect on the miners, the only hope for continued successful operation at Sulphur Bank may lie in a high price for quicksilver. At a rough estimate, the lowest price that would make mining profitable would be about $200 a flask.

RESERVES

Computation of ore reserves at Sulphur Bank is rendered difficult and uncertain by meager knowledge as to the results of underground prospecting and as to the grade of ore in the bodies left in the ground. Further uncertainty is caused by the spotty character of the ore deposits.

At the end of 1944, no assured ore was in sight at Sulphur Bank, and indicated ore was confined to unmined parts of the Herman pit and Empire-Babcock-Diamond shaft ore bodies. At least 50,000 tons of ore should remain in the downward extension of the Herman pit ore shoot, and this ore, judging from the ore already mined in that body, may be assumed to average 15 pounds of quicksilver to the ton. This represents an indicated reserve of about 9870 flasks. In the Empire-Babcock-Diamond shaft bodies, there are about 65,000 tons of indicated ore, conservatively estimated to average 10 pounds of quicksilver to the ton, which should yield 8550 flasks. Indicated reserves thus total 18,420 flasks from 115,000 tons of ore. To recover all this ore and that developed in the Herman shaft, it would be necessary to resort either to extremely costly surface mining or possibly to underground mining. Perhaps the bad effects of the hot waters and gases encountered in such mining could be offset in some degree by modern methods of ventilation, which would, however, add considerably to the mining costs.

Reserves of inferred ore that might be mined from downward extensions of Basalt and Parrott pits, from the area north of Canal pit, and from Wagon Spring pit are estimated to total at least 150,000 tons of 8-pound rock, which would yield 15,750 flasks.

These estimates would put the total reserves at Sulphur Bank at 34,170 flasks. But, as already pointed out, these reserves probably cannot be mined at a profit when quicksilver brings less than $200 a flask. As such a high price is not likely to be maintained in the foreseeable future, it may be many years before Sulphur Bank can be counted on as a producer.

MINERAL EXHIBIT AND STATISTICS

MINERAL STATISTICS FOR 1945

By Henry H. Symons *

INTRODUCTION

The counties of California have produced for some years past more than 50 different mineral substances, the total value of which was estimated at $488,244,000 for the year 1945.

At present, reports for most of the producers are at hand. Substances for which complete data are now compiled are summarized in this report. There was no record of commercial production during 1945 of bismuth, cadmium, calcium silicate, graphite, molybdenum ore, nickel, onyx and travertine, serpentine, shale oil, sulphur, titanium, tin, or zircon sand. There was a single producer each of bituminous rock, fluorspar, lithia, marble, mica, potash, and pyrite.

CEMENT

During 1945 the production of cement in California totaled 15,922,772 barrels, valued at $23,469,027 f.o.b. plant, of which 7,481,404 barrels, worth $9,686,081, came from five northern California mills, and 8,441,368 barrels, worth $13,782,946, came from six southern California mills. The 1945 output was an increase in both amount and value over that of 1944, which amounted to 14,599,752 barrels valued at $21,249,520.

Shipments of cement during 1945 were made from eleven mills in nine counties to the extent of 15,864,134 barrels, valued at $23,469,662 f.o.b. plant, as compared with 14,947,713 barrels, worth $22,482,794 in 1944. During the year five mills operated in northern California; one each in Calaveras, Contra Costa, San Mateo, Santa Clara, and Santa Cruz counties, which shipped a total of 7,446,421 barrels, valued at $9,659,943; and six mills in southern California; three in San Bernardino County and one each in Kern, Los Angeles, and Riverside counties, which shipped a total of 8,417,713 barrels, valued at $13,809,719.

A mill in San Bernardino County which has been idle for several years resumed production during 1944. The mill in Merced County was sold and the company has been liquidated.

The annual capacity of the California cement mills according to the U. S. Bureau of Mines was 27,740,000 barrels as of January 1, 1946, as compared with 27,390,000 barrels for January 1, 1945. During the year an average of 2,303 men were employed in the above mills.

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* Statistician and Curator, Division of Mines. Manuscript submitted for publication April 8, 1946.

ACCESSIONS TO THE EXHIBIT

By Henry H. Symons *

The museum of the State Division of Mines possesses an exceptionally fine collection of rocks and minerals of economic and academic value. It ranks among the first five such collections in North America and contains not only specimens of most of the known minerals found in California, but much valuable and interesting material from other States and foreign countries as well.

The exhibit is daily visited by service men, engineers, students, business men and prospectors as well as tourists and sightseers. In addition to its practical use in the economic development of California's mineral resources, the collection is a most valuable educational asset to the State and to San Francisco.

Mineral specimens suitable for exhibit purposes are solicited, and their donation will be appreciated by the Division of Mines, as well as by those who utilize the facilities of the collection.

Among the specimens received recently and catalogued for the exhibit are the following:

21225 SPONGE IRON made from Shasta iron ore, by U. S. Bureau of Mines for pilot-plant electric furnace preparation of ferro-alloys. Locality: Shasta County, California. Donor: U. S. Bureau of Mines by W. W. Stephens, February 1946. In Case 802.

21226 WILKEITE (yellow variety) a complex four acid mineral. From Crestmore, Riverside County, California. Donor: R. A. Crippen, February 1946. In Case 141.

21227 MONTICELLITE (brown) a calcium-mangnesium silicate, with vesuvianite (green) and crestmoreite (white). From Crestmore, Riverside County, California. Donor: R. A. Crippen, February 1946. In Case 129.

21228 BAUXITE $Al_2O_3.nH_2O$ a hydrous aluminum oxide. From Sibenik District, Dalmatia Province, Yugoslavia. Donor: Mounty Hess, February 1946. In Case 301.

21229 FOSSIL RESINS (fluoresce blue) in coal, found 10 miles northeast of Huntington, Utah, in Huntington Canyon. Donor: Adrian Nagelvoort, March 1946.

* Statistician and Curator, Division of Mines.

LIBRARY

LIBRARY REPORT

By James M. Little *

OUTLINE OF REPORT

INTRODUCTION

The library of the Division of Mines contains more than 6,000 selected volumes on mines, mining, and allied subjects. It is also the repository for reports and bulletins of technical departments of Federal and State governments and educational institutions both domestic and foreign. Current copies of newspapers published in the mining centers of the State are also available for reference.

The library and reading room are open to the public during the usual office hours, when the librarian may be freely called upon for all necessary assistance.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY AND UNITED STATES BUREAU OF MINES

The library of the Division of Mines has available for public reference the following publications of the United States Geological Survey: Annual Reports, Monographs, Professional Papers, Bulletins, Water-Supply Papers, Mineral Resources, Folios of the Geologic Atlas of the United States (broken file), Maps with Descriptive Text (broken file), Administrative Publications (broken file); and the following publications of the United States Bureau of Mines: Bulletins, Technical Papers, Economic Papers (broken file), Mineral Resources of the United States, Monographs (broken file), Reports of Investigations, Information Circulars.

Reports on California, recently received from the Bureau of Mines include:

United States Bureau of Mines

War Minerals Reports

357 McCormick Chromite Mine, Tuolumne County, California.

465 Shasta and California Iron Ore Deposits, Shasta County, California.

469 Effect of the War upon the Mineral Industry of California.

* Librarian, California State Division of Mines.

PUBLICATIONS OF STATE SURVEYS

A broken file of mining and geological publications, issued by the organizations listed below, may be consulted in the library of the Division of Mines.

Alabama Geological Survey, University.
Alaska (Territorial Commissioner of Mines), Juneau.
Arizona Bureau of Mines, Tucson.
Arkansas Geological Survey, Little Rock.
Colorado Bureau of Mines, Denver.
Connecticut Geological and Natural History Survey, Hartford.
Florida Department of Conservation, Tallahassee.
Georgia Division of Geology, Atlanta.
Idaho Bureau of Mines and Geology, Moscow.
Illinois Geological Survey, Urbana.
Indiana Division of Geology, Indianapolis.
Iowa Geological Survey, Des Moines.
State Geological Survey of Kansas, Lawrence.
Kentucky Geological Survey, Frankfort.
Louisiana Department of Conservation, New Orleans.
Maine State Geologist, Augusta.
Maryland Geological Survey, Baltimore.
Michigan Geological Survey, Lansing.
Minnesota Geological Survey, Minneapolis.
Mississippi State Geological Survey, University.
Missouri Bureau of Geology and Mines, Rolla.
Montana Bureau of Mines and Geology, Butte.
Nebraska Geological Survey, Lincoln.
Nevada State Bureau of Mines, Reno.
New Jersey Department of Conservation and Development, Trenton.
New Mexico Bureau of Mines and Mineral Resources, Socorro.
New York Science Division, Albany.
North Carolina Geological and Economic Survey, Chapel Hill.
North Dakota Geological Survey, Grand Forks.
Ohio Geological Survey, Columbus.
Oklahoma Geological Survey, Norman.
Oregon State Department of Geology and Mineral Industries, Portland.
Pennsylvania Topographic and Geological Survey, Harrisburg.
South Dakota State Geological Survey, Vermillion.
Tennessee Division of Geology, Nashville.
Texas Bureau of Economic Geology, Austin.
Virginia Geological Survey, University.
Washington State Department of Conservation and Development, Pullman.
West Virginia Geological Survey, Morgantown.
Wisconsin Geological and Natural History Survey, Madison.
Wyoming Geological Survey, Cheyenne.

PUBLICATIONS OF FOREIGN GOVERNMENTS

Publications of the following foreign governments are received and current issues may be consulted in the library. Earlier issues of foreign-language publications have been loaned to the California Academy of Sciences in Golden Gate Park, because of the limited storage space at the Division's offices in the Ferry Building. They may, however, be consulted at the Academy.

Alberta Research Council, Edmonton.
Argentina Direccion General de Minas y Geologica, Buenos Aires.
Brazil, Divisao de Geologica e Mineralogie, Rio de Janerio.
Brazil, Ministry de Foreign Affairs, Rio de Janerio.
British Columbia Minister of Mines, Victoria.
British Museum of Natural History, London.
Canada Department of Mines, Ottawa.
Cuerpo de Ingenieros de Minas del Peru, Lima.
Department of Scientific and Industrial Research, Wellington, N. Z.
Federated Malay States, Geological Survey, Kuala Lumpur.
Geological Service of Minas Geraes, Bella Harizonte, Brazil.
Geological Survey of Scotland.
Geological Survey, West Australia, Perth.
Gouvernment General de L'Afrique Equatoriale Francaise, Service des Mines, Brazzaville.
Gouvernment General de L'Afrique Occidentale Francaise, Service des Mines, Dakar.
Instituto Historica e Geographico, Rio de Janerio.
Mexico, Universidad Nacional Autonoma de Mexico, Mexico, D. F.
Ministerio da Agricultura, Divisao de Geologia e Mineralogia, Rio de Janerio.

Ministerio de Agricultura, Direccion de Minas y Geologia, Buenos Aires, Argentina.
Ministerio de Fomento y Obras Publicas, Lima, Peru.
Museo de Historia Natural de Montevideo, Uruguay.
Museu Nacional, Rio de Janerio, Brazil.
New South Wales, Department of Mines, Sydney.
New Zealand Geological Survey Branch, Wellington.
Nova Scotia Department of Public Works and Mines, Halifax.
Ontario Department of Mines, Toronto, Canada.
Quebec, Bureau of Mines, Quebec.
Queensland Department of Mines, Brisbane, Australia.
Queensland Government Mining Journal, Brisbane.
Republica Argentina, Direccion de Minas, Geologia e Hidrogeologia, Buenos Aires.
Royal Society of South Australia, Department of Mines, Adelaide.
Secretaria de la Economia Nacional, Direccion General de Minas y Petroleo, Mexico, D. F.
South Australia Department of Mines, Adelaide.
Universidad Nacional de Tucuman, Tucuman, Argentina.
Victoria, Department of Mines, Melbourne, Australia.
Western Australia Geological Survey, Perth.

PUBLICATIONS OF DOMESTIC SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academy of Natural Sciences of Philadelphia.
American Association of Petroleum Geologists, Tulsa, Oklahoma.
American Geographical Society of New York.
American Institute of Mining and Metallurgical Engineers, New York.
American Journal of Science, New Haven, Conn.
California Academy of Sciences, San Francisco.
Carnegie Institution of Washington.
Cleveland Museum of Natural History, Cleveland, Ohio.
Colorado College, Colorado Springs, Col.
Colorado School of Mines, Golden, Col.
Colorado Scientific Society, Denver.
Commonwealth Club, San Francisco.
Economic Geology, Lancaster, Pa.
Field Museum of Natural History, Chicago.
Franklin Institute, Lancaster, Pa.
Geological Society of America, Baltimore.
Journal of Geology, Chicago.
Journal of Paleontology, Chicago.
Mineralogical Society of America, Menasha, Wis.
Michigan College of Mining and Technology, Houghton.
Mining and Metallurgical Society of America, New York.
Missouri School of Mines and Metallurgy, Rolla.
National Research Council, Washington, D. C.
National Speleological Society, Washington, D. C.
New York Academy of Sciences, New York.
New York State Museum, Albany.
Pennsylvania State College, State College.
San Diego Society of Natural History, San Diego, California.
Santa Barbara Museum of Natural History, Santa Barbara, California.
Seismological Society of America, Stanford University.
Sierra Club, San Francisco.
Southern California Academy of Sciences, Los Angeles.
Stanford University, California.
University of California Publications in Engineering, Geography and Geology, Berkeley.
University of Harvard, Department of Mineralcgy and Petrography, Cambridge, Mass.

PUBLICATIONS OF FOREIGN SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academia de Ciencias y Artes de Barcelona, Spain.
Australian Museum, Sydney.
Canadian Institute of Mining and Metallurgy, Montreal.
Chamber of Mines of West Australia, Kalgoorlie.
Geological Society of London.
Institution of Mining and Metallurgy, London.
Instituto Geologica de Mexico, Mexico, D. F.
Journal of the Royal College of Science, London.
Mexico Journal, Compilation and Translation Department, San Antonio, Texas.
Philippine Journal of Science, Manila.
Royal Society of South Australia, Adelaide.
Transvaal Chamber of Mines, Johannesburg.

CURRENT MAGAZINES

Current issues of the technical magazines listed below are on file in the reading room of the library, and may be consulted.

ADT Transmitted, New York.
Asbestos, Philadelphia.
Bakelite Review, New York.
Brick and Clay Record, Chicago.
California Highways and Public Works, Sacramento.
California Magazine of the Pacific, San Francisco.
California Mining Journal, Auburn.
California Oil World, Los Angeles.
California Safety News, San Francisco.
Canadian Mining Journal, Gardenvale, Quebec.
Chemical and Metallurgical Engineering, New York.
Chemical Industries, Philadelphia.
Deco Trefoil, Denver.
Desert Magazine, El Centro.
Du Pont Magazine, Wilmington, Del.
Driller, South Milwaukee,
Engineering and Mining Journal, New York.
Fairbanks-Morse News, Chicago.
Foote Prints, Philadelphia.
Fusion Facts, Whittier.
Gemmologist, London.
Grizzly Bear, Los Angeles.
Hercules Mixer, Wilmington, Del.
Highway Magazine, Middletown, Ohio.
Highway Traveler, Cleveland.
Independent Monthly, Tulsa, Oklahoma.
Johnson National Distillers Journal, St. Paul.
Light, Cleveland.
Light Metal Age, Chicago.
Lubrication, New York.
Marion Groundhog, Marion, Ohio.
Metals and Alloys, Pittsburgh, Pa.
Mineralogist, Portland, Ore.
Mines Magazine, Denver.
Mining and Contracting Review, Salt Lake City.
Mining and Geological Journal, Melbourne, Victoria, Australia.
Mining and Industrial News, San Francisco.
Mining and Metallurgy, New York.
Mining Congress Journal, Washington, D. C.
Mining Journal, Phoenix, Arizona.
Mining Journal, London.
Mining World, Seattle.
Nickel Steel Topics, New York.
Oil and Gas Journal, Tulsa, Oklahoma.
Oil, Paint and Drug Reporter, New York.
Oil Weekly, Houston, Texas.
Pacific Road Builder, San Francisco.
Pacific Purchaser, San Francisco.
Pay Dirt, Phoenix, Arizona.
Petroleum World, Los Angeles.
Pit and Quarry, Chicago.
Rock Products, Chicago.
Rocks and Minerals, Peekskill, N. Y.
Scientific American, New York.
Silicate, P's & Q's, Berkeley.
Standard Oil Bulletin, San Francisco.
Storage Battery Power, West Orange, N. J.

NEWSPAPERS

Current issues of the following papers are received and kept on file in the library:

Alaska Weekly, Seattle, Washington.
Amador Dispatch, Jackson, California.
Banner, Sonora, California.
Barstow Printer, Barstow, California.
Bridgeport Chronicle-Union, Bridgeport, California.
Calaveras Californian, Angels Camp, California.
Calaveras Prospect, San Andreas, California.
Daily Commercial News, San Francisco, California.
Del Norte Triplicate, Crescent City, California.
Denver Mining Record, Denver, Colorado.
Inyo Independent, Independence, California.
Inyo Register, Bishop, California.

Las Vegas Age, Las Vegas, Nevada.
Livermore Herald, Livermore, California.
Los Angeles Times, Los Angeles, California.
Mariposa Gazette, Mariposa, California.
Mining Press, Reno, Nevada.
Mohave Miner, Kingman, Arizona.
Morning Union, Grass Valley, California.
Mountain Messenger, Downieville, California.
Needles Nugget, Needles, California.
Oroville Mercury Register, Oroville, California.
Placer Herald, Auburn, California.
Placerville Times, Placerville, California.
Plumas Independent, Quincy, California.
Randsburg Times, Randsburg, California.
Tehachapi News, Tehachapi, California.
Terra Bella News, Terra Bella, California.
Tuolumne Independent, Sonora, California.
Tuolumne Prospector, Tuolumne, California.
Union Democrat, Sonora, California.
Weekly Trinity Journal, Weaverville, California.
Yreka Journal, Yreka, California.

NEW BOOKS

Field, R. M., An Outline of the Principles of Geology, 3rd Ed., 209 pp., Barnes & Noble, Inc., New York, 1941.

Reich, H. J., Theory and Applications of Electron Tubes, 2nd Ed., 716 pp., McGraw-Hill Book Co., New York, 1944.

Ries, H., Clays, Their Occurrence Properties and Uses, 3rd Ed., 613 pp., John Wiley & Sons, Inc., New York, 1927.

Sachanen, A. N., The Chemical Constituents of Petroleum, 451 pp., Reinhold Publishing Corp., New York, 1945.

Smith, H. D., Atomic Energy for Military Purposes, 308 pp., Princeton University Press, Princton, 1945.
(F. W. Bradley Memorial Book Fund).

Webster, R., Introductory Gemology, 181 pp., Gemological Institute of America, Los Angeles, 1945.

SERVICES OF THE DIVISION OF MINES

The Division of Mines (formerly State Mining Bureau) is maintained for the purpose of assisting in all possible ways in the development of California's mineral resources.

As one means of offering tangible service to the mining public, the State Mineralogist for many years has issued an annual or a biennial report reviewing in detail the mines and mineral deposits of the various counties.

As a progressive step in advancing the interests of the mineral industry, and as permitting earlier distribution to the public, publication of the Annual Report of the State Mineralogist in the form of monthly chapters was begun in January 1922, and continued until March 1923. Owing to a lack of funds for printing this was changed to a quarterly publication, beginning in September 1923. For the same reason, beginning with the January 1924 issue, it became necessary to charge a subscription price. This covers approximately the cost of printing.

Pages are numbered consecutively throughout the year and an index to the complete report is included annually in the closing number.

Beginning with the 1930 issues, the activities and progress of the Geologic Branch are recorded also in these quarterly chapters. The important part that geology plays in the economic development of our mineral resources is further recognized in the change of title from *Mining in California* to California Journal of Mines and Geology, beginning with the January 1933 chapter.

While current activities of all descriptions are covered in these chapters, the practice of issuing from time to time technical reports on special subjects will be continued as well. A list of such reports now available is appended hereto, and the names of new bulletins will be added in the future as they are completed.

The chapters are subject to revision, correction and improvement. Constructive suggestions from the mining public will be gladly received, and are invited.

The one aim of the Division of Mines is to increase its usefulness and to stimulate the intelligent development of the wonderful, latent resources of the State of California.

TYPES OF REPORTS

In general the reports presented in these chapters are grouped into three classes:

1. Mines and mineral resources of a given county or area (describing kind, character, distribution and extent of development).

2. Specific economic and industrial mineral products (listing and describing the resources over the entire State of a given mineral substance, e.g., feldspar).

3. Geological reports on specific areas (recording results and conclusions with maps, derived from field studies; and tied in with economic possibilities and developments).

Reports of District Mining Engineers

In 1919-1920 the Mining Bureau was organized into four main geographical divisions, with the field work delegated to a mining engineer in each district, working out from field offices that were established in Redding, Auburn, San Francisco and Los Angeles, respectively. This move brought the office into closer personal contact with operators, and it has many advantages over former methods of conducting field work, including lower traveling-expense bills for the Bureau's engineers. In 1923 the Redding and Auburn field offices were consolidated and moved to Sacramento.

The Redding office was reestablished in 1928, and the boundaries of each district adjusted. The counties now included in each of the four divisions and the locations of the branch offices are shown on the frontispiece outline map of the State.

Reports of mining activities and development in each district, prepared by the District Engineer, will continue to appear under the proper field division heading.

Special Articles

Detailed technical reports on special subjects, the result of research work or extended field investigations, will continue to be issued as separate bulletins by the Division, as has been the custom in the past.

Shorter and less elaborate technical papers and articles by members of the staff and others are published in each number of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

These special articles cover a wide range of subjects both of historical and current interest; descriptions of new processes, or metallurgical and industrial plants, new mineral occurrences, and interesting geological formations, as well as articles intended to supply practical and timely information on the problems of the prospector and miner, such as the text of new laws and official regulations and notices affecting the mineral industry.

MAIL AND FILES

The Division of Mines maintains, in addition to its correspondence files and the library, a mine file which includes original reports on the various mines and mineral properties of all kinds in California.

During each quarterly period there are several thousand letters received and answered at the San Francisco office alone, covering almost every phase of prospecting, mining and developing mineral deposits, reduction problems, marketing of refined products and mining law. In addition to this, hundreds of oral questions are answered daily, both at the main office and the district offices, for the many inquirers who come in for personal interviews and to consult the files and library.

The library has a card-file system for references to individual California mines, occurring in the publications of the Division of Mines, in the Mining and Scientific Press, the Engineering and Mining Journal, and the Arizona Mining Journal.

COMMERCIAL MINERAL NOTES

The producer and consumer of mineral products are mutually dependent upon each other for their prosperity, and one of the most direct aids rendered by this Division to the mining industry in the past

has been that of bringing producers and consumers into direct touch with each other.

This work has been carried on largely by correspondence, supplemented by personal consultation. Lists of buyers of all the commercial minerals produced in California have been made available to producers upon request, and likewise the owners of undeveloped deposits of various minerals, and producers of them, have been made known to those looking for raw mineral products.

When the publication of *Mining in California* was on a monthly basis, current inquiries from buyers and sellers were summarized and lists of mineral products or deposits 'wanted' or 'for sale' included in each issue.

It is important that inquiries of this nature reach the mining public as soon as possible and in order to avoid the delay incident to the present quarterly publication of CALIFORNIA JOURNAL OF MINES AND GEOLOGY, these lists are now issued monthly in the form of a mimeographed sheet under the title of *Commercial Mineral Notes*, and sent to those on the mailing list of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

EMPLOYMENT SERVICE

Following the establishment of the Mining Division branch offices in 1919, a free technical employment service was offered as a mutual aid to mine operators and technical men for the general benefit of the mineral industry.

Briefly summarized, men desiring positions are registered, the cards containing an outline of the applicant's qualifications, position wanted, salary desired, etc., and as notices of 'positions open' are received, the names and addresses of all applicants deemed qualified are sent to the prospective employer for direct negotiations.

Telephone and telegraphic communications are also given immediate attention.

Technical men, or those qualified for supervisory positions, and vacancies of like nature only, are registered, as no attempt will be made to supply mine and mill labor.

Registration cards for the use of both prospective employers and employees may be obtained upon request, and a cordial invitation is extended to the industry to make free use of the facilities afforded. Parties interested should communicate direct with our San Francisco office.

DETERMINATION OF MINERAL SAMPLES

Samples (limited to two in one month) of any mineral found in the State may be sent to the Division of Mines for identification, and the same will be classified free of charge. No samples will be determined if received from points outside the State. It must be understood that no assays, or quantitative determinations will be made. Samples should be in lump form if possible, and marked plainly with name of sender on outside of package, etc. No samples will be received unless delivery charges are prepaid. A letter should accompany sample, giving locality where mineral was found and the nature of the information desired.

PUBLICATIONS OF THE DIVISION OF MINES

During the past sixty-five years, in carrying out the provisions of the organic act creating the former California State Mining Bureau, there have been published many reports, bulletins and maps which go to make up a library of detailed information on the mineral industry of the State, a large part of which could not be duplicated from any other source.

One feature that has added to the popularity of the publications is that many of them have been distributed without cost to the public, and even the more elaborate ones have been sold at a price which barely covers the cost of printing.

Owing to the fact that funds for the advancing of the work of this department have usually been limited, the reports and bulletins mentioned are printed in limited editions many of which are now entirely exhausted.

Copies of such publications are available for reference, however, in the offices of the Division of Mines, in the Ferry Building, San Francisco 11; State Building, Los Angeles 12; State Office Building No. 1, Sacramento 14; Redding; and Division of Oil and Gas at Santa Barbara, Santa Paula, Taft, Bakersfield, Coalinga. They may also be found in many public, private and technical libraries in California and other states and foreign countries.

A catalog of all publications from 1880 to 1917, giving a synopsis of their contents, is issued as Bulletin No. 77.

Publications in stock may be obtained postpaid by addressing the San Francisco, Los Angeles or Sacramento offices and enclosing the requisite amount.

Remittances of stamps in an amount not to exceed 26 cents, currency or coin will be accepted at sender's risk. Payment is preferred in the form of money orders.

Money orders should be made payable to the Division of Mines.

Write for latest revised price list.

NOTE.—The Division of Mines frequently receives requests for some of the early Reports and Bulletins now out of print, and it will be appreciated if parties having such publications and wishing to dispose of them will advise this office.

REPORTS

Asterisks (**) indicate the publication is out of print. — Price (including postage and sales tax)

Publication	Price (including postage and sales tax)
**Report I of the State Mineralogist, 1880, 43 pp. Henry G. Hanks	----
**Report II of the State Mineralogist, 1882, 514 pp., 4 illustrations, 1 map. Henry G. Hanks	----
**Report III of the State Mineralogist, 1883, 111 pp., 21 illustrations. Henry G. Hanks	----
**Report IV of the State Mineralogist, 1884, 410 pp., 7 illustrations. Henry G. Hanks	----
**Report V of the State Mineralogist, 1885, 234 pp., 15 illustrations, 1 geological map. Henry G. Hanks	----
**Report VI of the State Mineralogist, Part 1, 1886, 145 pp., 3 illustrations, 1 map. Henry G. Hanks	----
Part II, 1887, 222 pp., 36 illustrations. William Irelan, Jr. Price $0.75, sales tax $0.02	$0.77
**Report VII of the State Mineralogist, 1887, 315 pp. William Irelan, Jr.	----
**Report VIII of the State Mineralogist, 1888, 948 pp., 122 illustrations. William Irelan, Jr.	----
Report IX of the State Mineralogist, 1889, 352 pp., 57 illustrations, 2 maps. William Irelan, Jr. Price $1.15, sales tax $0.03	1.18
**Report X of the State Mineralogist, 1890, 983 pp., 179 illustrations, 10 maps. William Irelan, Jr.	----
Report XI (First Biennial) of the State Mineralogist, for the two years ending September 15, 1892, 612 pp., 73 illustrations, 4 maps. William Irelan, Jr. Price $1.50, sales tax $0.04	1.54
**Report XII (Second Biennial) of the State Mineralogist, for the two years ending September 15, 1894, 541 pp., 101 illustrations, 5 maps. J. J. Crawford	----
**Report XIII (Third Biennial) of the State Mineralogist, for the two years ending September 15, 1896, 726 pp., 93 illustrations, 1 map. J. J. Crawford	----
Chapters of the State Mineralogist's Report XIV, Biennial Period, 1913-1914, Fletcher Hamilton:	
**Mines and Mineral Resources, Amador, Calaveras and Tuolumne Counties, 172 pp., paper	----
Mines and Mineral Resources, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma and Yolo Counties, 208 pp., paper Price $0.50, sales tax $0.01	.51
Mines and Mineral Resources, Del Norte, Humboldt and Mendocino Counties, 59 pp., paper Price $0.35, sales tax $0.01	.36
Mines and Mineral Resources, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin and Stanislaus Counties, 220 pp., paper Price $0.75, sales tax $0.02	.77
Mines and Mineral Resources of Imperial and San Diego Counties, 113 pp., paper Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, Shasta, Siskiyou and Trinity Counties, 180 pp., paper	----
**Report XIV of the State Mineralogist, for the Biennial Period 1913-1914, Fletcher Hamilton, 1915: A General Report on the Mines and Mineral Resources of Amador, Calaveras, Tuolumne, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma, Yolo, Del Norte, Humboldt, Mendocino, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, San Diego, Imperial, Shasta, Siskiyou and Trinity Counties, 974 pp., 275 illustrations, cloth	----
Chapters of the State Mineralogist's Report XV, Biennial Period, 1915-1916, Fletcher Hamilton:	
**Mines and Mineral Resources, Alpine, Inyo and Mono Counties, 176 pp., paper	----
Mines and Mineral Resources, Butte, Lassen, Modoc, Sutter and Tehama Counties, 91 pp., paper Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, El Dorado, Placer, Sacramento and Yuba Counties, 198 pp., paper	----

REPORTS—Continued

Asterisks (**) indicate the publication is out of print.	Price (including postage and sales tax)
**Mines and Mineral Resources, Monterey, San Benito, San Luis Obispo, Santa Barbara and Ventura Counties, 183 pp., paper	----
**Mines and Mineral Resources, Los Angeles, Orange and Riverside Counties, 136 pp., paper	----
**Mines and Mineral Resources, San Bernardino and Tulare Counties, 186 pp., paper	----
**Report XV of the State Mineralogist, for the Biennial Period 1915-1916, Fletcher Hamilton, 1917: A General Report on the Mines and Mineral Resources of Alpine, Inyo, Mono, Butte, Lassen, Modoc, Sutter, Tehama, Placer, Sacramento, Yuba, Los Angeles, Orange, Riverside, San Benito, San Luis Obispo, Santa Barbara, Ventura, San Bernardino and Tulare Counties, 990 pp., 413 illustrations, cloth	----
Chapters of the State Mineralogist's Report XVI, Biennial Period, 1917-1918, Fletcher Hamilton:	
**Mines and Mineral Resources of Nevada County, 270 pp., paper	----
Mines and Mineral Resources of Plumas County, 188 pp., paper Price $0.50, sales tax $0.01	$0.51
Mines and Mineral Resources of Sierra County, 144 pp., paper Price $0.75, sales tax $0.02	.77
Report XVII of the State Mineralogist, 1920, 'Mining in California during 1920,' Fletcher Hamilton; 562 pp., 71 illustrations, cloth Price $2.50, sales tax $0.06	2.56
Report XVIII of the State Mineralogist, 1922, 'Mining in California,' Fletcher Hamilton. Chapters published monthly beginning with January, 1922:	
**January, **February, **March, April, May, June, July, August, September, October, November, December, 1922 Price $0.30, sales tax $0.01	.31
Chapters of Report XIX of the State Mineralogist, 'Mining in California,' Fletcher Hamilton and Lloyd L. Root. January, February, March, September, 1923 Price $0.30, sales tax $0.01	.31
Chapters of Report XX of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly. January, April,** July, October, 1924, per copy Price $0.30, sales tax $0.01	.31
Chapters of Report XXI of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1925. Mines and Mineral Resources of Sacramento, Monterey and Orange Counties Price $0.30, sales tax $0.01	.31
**April, 1925. Mines and Mineral Resources of Calaveras, Merced, San Joaquin, Stanislaus and Ventura Counties	----
**July, 1925. Mines and Mineral Resources of Del Norte, Humboldt and San Diego Counties	----
**October, 1925. Mines and Mineral Resources of Siskiyou, San Luis Obispo and Santa Barbara Counties	----
Chapters of Report XXII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
**January, 1926. Mines and Mineral Resources of Trinity and Santa Cruz Counties	----
**April, 1926. Mines and Mineral Resources of Shasta, San Benito and Imperial Counties	----
July, 1926. Mines and Mineral Resources of Marin and Sonoma Counties Price $0.30, sales tax $0.01	.31
**October, 1926. Mines and Mineral Resources of El Dorado and Inyo Counties, also report on Minaret District, Madera County	----
Chapters of Report XXIII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1927. Mines and Mineral Resources of Contra Costa County; Santa Catalina Island Price $0.30, sales tax $0.01	.31

REPORTS—Continued

Asterisks (**) indicate the publication is out of print. Price (including postage and sales tax)

April, 1927. Mines and Mineral Resources of Amador and Solano Counties Price $0.30, sales tax $0.01	$0.31
**July, 1927. Mines and Mineral Resources of Placer and Los Angeles Counties	--
October, 1927. Mines and Mineral Resources of Mono County Price $0.30, sales tax $0.01	.31
Chapters of Report XXIV of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1928. Mines and Mineral Resources of Tuolumne County Price $0.30, sales tax $0.01	.31
April, 1928. Mines and Mineral Resources of Mariposa County Price $0.30, sales tax $0.01	.31
**July, 1928. Mines and Mineral Resources of Butte and Tehama Counties	----
October, 1928. Mines and Mineral Resources of Plumas and Madera Counties Price $0.30, sales tax $0.01	.31
Chapters of Report XXV of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
**January, 1929. Mines and Mineral Resources of Lassen, Modoc and Kern Counties; also on Special Placer Machines	----
**April, 1929. Mines and Mineral Resources of Sierra, Napa, San Francisco and San Mateo Counties	----
July, 1929. Mines and Mineral Resources of Colusa, Fresno and Lake Counties Price $0.30, sales tax $0.01	.31
October, 1929. Mines and Mineral Resources of Glenn, Alameda, Mendocino and Riverside Counties Price $0.30, sales tax $0.01	.31
Chapters of Report XXVI of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1930. Mines and Mineral Resources of Santa Clara County; also Barite in California Price $0.40, sales tax $0.01	.41
**April, 1930. Mines and Mineral Resources of Nevada County; also Mineral Paint Materials in California	----
**July, 1930. Mines and Mineral Resources of Yuba and San Bernardino Counties; also Commercial Grinding Plants in California	----
October, 1930. Mines and Mineral Resources of Butte, Kings and Tulare Counties; also Geology of Southwestern Mono County (Preliminary) Price $0.40, sales tax $0.01	.41
Chapters of Report XXVII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1931. Preliminary Report of Economic Geology of the Shasta Quadrangle. Beryllium and Beryl. The New Tariff and Nonmetallic Products. Crystalline talc. Decorative effects in Concrete Price $0.40, sales tax $0.01	.41
April, 1931. Stratigraphy of the Kreyenhagen Shale. Diatoms and Silicoflagellates of the Kreyenhagen Shale. Foraminifera of the Kreyenhagen Shale. Geology of Santa Cruz Island Price $0.40, sales tax $0.01	.41
**July, 1931. (Yuba, San Bernardino Counties.) Feldspar, Silica, Andalusite and Cyanite Deposits of California. Note on a Deposit of Andalusite in Mono County; its occurrence and chemical importance. Bill creating Trinity and Klamath River Fish and Game District and its effect upon mining	----
October, 1931. (Alpine County.) Geology of the San Jacinto Quadrangle south of San Gorgonio Pass, California. Notes on Mining Activities in Inyo and Mono Counties in July, 1931 Price $0.40, sales tax $0.01	.41
Chapters of Report XXVIII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1932, Economic Mineral Deposits of the San Jacinto Quadrangle. Geology and Physical Properties of Building Stone from Car. mel Valley. Contributions to the Study of Sediments. Sediments of Monterey Bay. Sanbornite Price $0.40, sales tax $0.01	.41

REPORTS—Continued

Asterisks (**) indicate the publication is out of print.

Price (including postage and sales tax)

**April, 1932. Elementary Placer Mining Methods and Gold Saving Devices. The Pan, Rocker and Sluice Box. Prospecting for Vein Deposits. Bibliography of Placer Mining---- ----

**Abstract from April quarterly; Elementary Placer Mining Methods and Gold Saving Devices. Types of Deposits, Simple Equipment. Special Machines. Dry Washing. Black Sand Treatment. Marketing of Products. Placer Mining Areas. Laws. Prospecting for Quartz Veins. Bibliography (mimeographed)---- ----

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Bulletin No. 111. **California Mineral Production and Directory of Mineral Producers for 1934**, by Henry H. Symons, 334 pp., paper	----
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**Bulletin. Reconnaissance of the Colorado Desert Mining District. By Stephen Bowers, 1901. 19 pp. 2 illustrations. Paper	----
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**Register of Mines, with Map, Lake County	----
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**Map of El Dorado County, Showing Boundaries, National Forests	----
**Map of Madera County, Showing Boundaries, National Forests	----
**Map of Placer County, Showing Boundaries, National Forests	----
**Map of Sierra County, Showing Boundaries, National Forests	----
**Map of Siskiyou County, Showing Boundaries, National Forests	----
**Map of Tuolumne County, Showing Boundaries, National Forests	----
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**Map of Plumas County	----
**Map of Trinity County	----
**Map of Tuolumne County	----
**Geographical Map of Inyo County. Scale 1 inch equals 4 miles	----
**Map of California accompanying Bulletin No. 89, showing generalized classification of land with regard to oil possibilities. Map only, without Bulletin	----
**Geologic Map of California, 1916. Scale 1 inch equals 12 miles. Shows railroads, highways, post offices and other towns. Geological details lithographed in 23 colors. Mounted	----
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Jamesburg Quadrangle Geologic Map and Structure Section, accompanying report on geology of area in April 1944 Chapter of Report XL, sold separately ---- Price per set $0.40, sales tax $0.01 .41

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The following maps are on sale at the State Division of Oil and Gas, Ferry Building, San Francisco, and the various branch offices. The maps are revised as development work advances and ownerships change. Price includes postage and sales tax.

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44	Mesa, Santa Barbara County	1.50
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49	Fruitvale, Kern County	1.00
50	Wilmington, Los Angeles County	1.25
51	Santa Maria Valley, Santa Barbara County	1.00
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53	Rio Bravo and Greeley, Kern County	1.00
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55	Canal, Canfield Ranch, Coles Levee, Strand, Ten Section, Kern County	1.25
56	Paloma, Kern County	1.25
57	Rio Vista (gas), Sacramento, Solano, and Contra Costa Counties	1.00
58	Trico Gas, Kern, Kings and Tulare Counties	1.00
59	Raisin City, Helm and Riverdale, including Wheatville area, Fresno County	1.25

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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

WALTER W. BRADLEY State Mineralogist

Vol. 42 JULY 1946 No. 3

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

QUARTERLY CHAPTER
OF
STATE MINERALOGIST'S REPORT XLII

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57415

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State Mineralogist

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SURFACE PLANT AT CONTACT MINE, FEBRUARY 1946
Western Mayacmas quicksilver district, Sonoma County
Photo by courtesy of H. G. Walker

CONTENTS

PLATES


INDEX MAP
OF
ECONOMIC MINERALS
IN
CALIFORNIA
AND THE
DISTRICTS OF THE DIVISION OF MINES
SCALE
0
50
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CALIFORNIA STATE DIVISION OF MINES
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DISTRICT OFFICES OF THE DIVISION OF MINES
San Francisco (main office)
Los Angeles
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BOUNDARIES OF THE DISTRICTS
124°
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116°
115°
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41°
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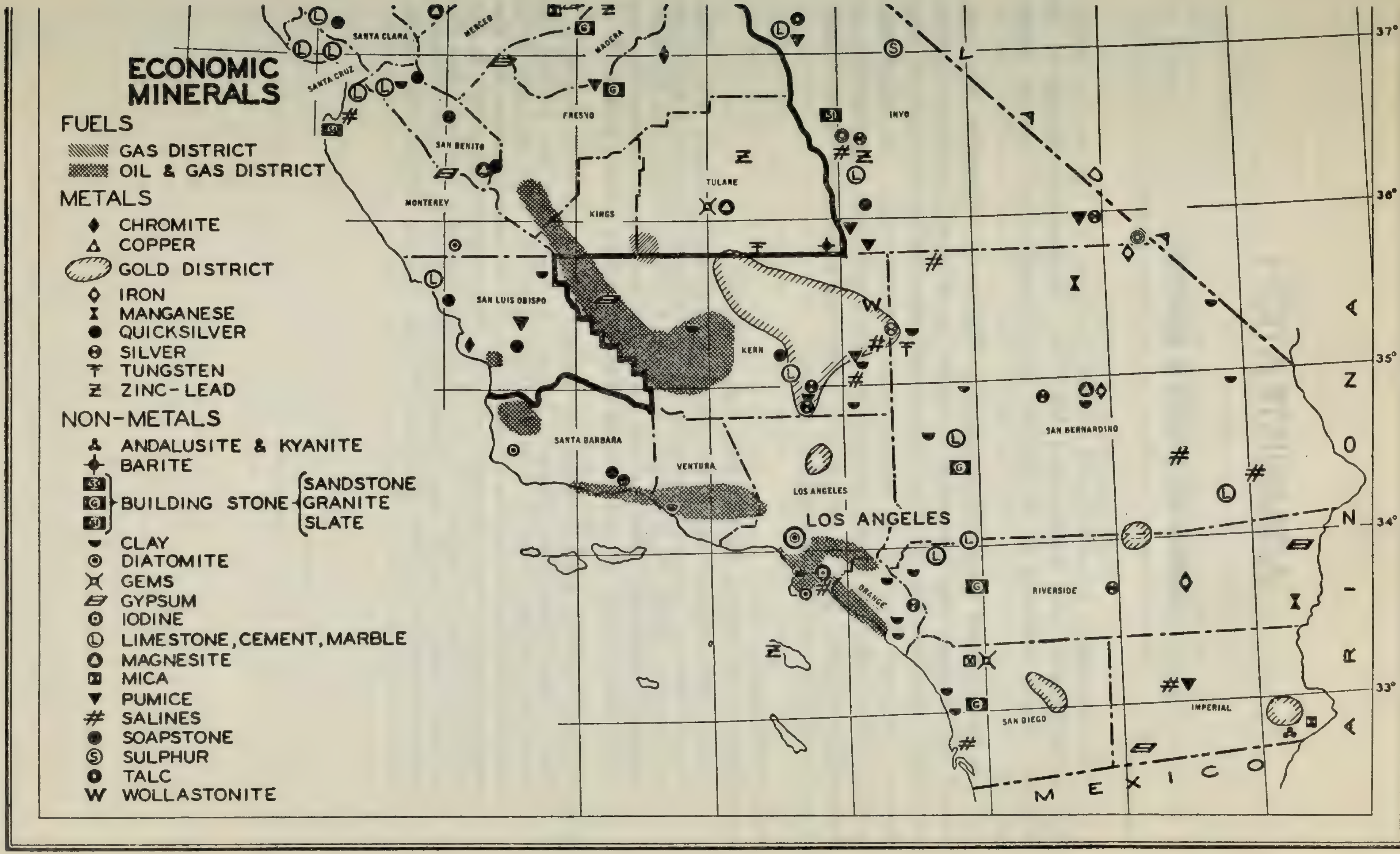
39°
38°
OREGON
NEVADA
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
REDDING
LASSEN
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
NEVADA
YUBA
LAKE
COLUSA
PLACER
SUTTER
EL DORADO
YOLO
SACRAMENTO
ALPINE
SONOMA
NAPA
AMADOR
SOLANO
CALAVERAS
MARIN
SAN JOAQUIN
MONO
TUOLUMNE
CONTRA COSTA
SAN FRANCISCO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO


ECONOMIC MINERALS
FUELS
GAS DISTRICT
OIL & GAS DISTRICT
METALS
CHROMITE
COPPER
GOLD DISTRICT
IRON
MANGANESE
QUICKSILVER
SILVER
TUNGSTEN
ZINC-LEAD
NON-METALS
ANDALUSITE & KYANITE
BARITE
BUILDING STONE
SANDSTONE
GRANITE
SLATE
CLAY
DIATOMITE
GEMS
GYPSUM
IODINE
LIMESTONE, CEMENT, MARBLE
MAGNESITE
MICA
PUMICE
SALINES
SOAPSTONE
SULPHUR
TALC
WOLLASTONITE
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
FRESNO
INYO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
NEVADA
ARIZONA
MEXICO
37°
36°
35°
34°
33°

ADMINISTRATION

ADMINISTRATIVE REPORT

By Walter W. Bradley, State Mineralogist

Personnel

The temporary appointment of Dr. Arthur A. Center, as metallurgical engineer, was terminated May 1st. Permanent filling of the position awaits creating of an eligible list through a civil service examination.

The incumbent State Mineralogist, Walter W. Bradley, has presented his request for retirement under the State Employees Retirement Act, effective August 1st. He joined the staff of the State Mining Bureau, January 8, 1912, as mining engineer-librarian. He filled, successively, the positions of field assistant, statistician and curator, deputy State mineralogist, and on August 1, 1928 was appointed State Mineralogist and Chief of the Division of Mines.

New Publications

CALIFORNIA JOURNAL OF MINES AND GEOLOGY

October 1945, being Chapter 4 of State Mineralogist's Report XLI. This chapter contains: *Current Notes* of the Geologic Branch; *Pine Creek and Adamson Tungsten Mines, Inyo County,* with maps; *Index to Topographic Quadrangles of California; Flow-sheet of American Potash and Chemical Corporation at Searles Lake; Accessions to the Mineral Exhibit; Library Report.*

BULLETIN 129, IRON RESOURCES OF CALIFORNIA. Advance preprints:

Part A, *Eagle Mountains, Riverside County;* Part B, *Lava Bed District, San Bernardino County;* Part C, *Iron Mountain and Iron King Deposits, Silver Lake District, San Bernardino County;* Part D, *Old Dad Mountain, San Bernardino County;* Part E, *Cave Canyon, San Bernardino County;* Part F, *Vulcan Deposit, San Bernardino County;* Part G, *Iron Hat (Ironclad), San Bernardino County;* Part H, *Ship Mountains, San Bernardino County;* Part I, *Minarets Deposits of Iron Mountain, Madera County;* Part J, *Hirz Mountain, Shasta County.*

BIENNIAL REPORT OF THE STATE MINERALOGIST

GENERAL WARREN T. HANNUM, *Director*
Department of Natural Resources
Sacramento, California

SIR: Herein I have the honor to present the biennial report of the State Mineralogist, as required by law, for transmittal to His Excellency, Governor Earl Warren, covering the work and activities of the Division of Mines of the Department of Natural Resources for the period July 1, 1944 to June 30, 1946.

HISTORICAL SUMMARY

April 16, 1946 marked the 66th anniversary of the signing by Governor George C. Perkins (later United States Senator for California) of the bill introduced by Assemblyman Joseph Wasson of Mono and Inyo Counties, by which the ''State Mining Bureau'' was created with headquarters in San Francisco. Under authority of that act, Henry G. Hanks was shortly thereafter commissioned the first ''State Mineralogist'' of California.

Previously there had been two short-lived ''geological surveys'' in this State; the first under John B. Trask as State Geologist, 1853-1856; the second under Josiah D. Whitney, 1860-1873. The fundamental idea underlying the creation of the State ''Mining Bureau'' was that it should be concerned primarily with an economic developmental survey of California's mineral resources and their utilization rather than solely geology. Provision was also made, however, in the organic act that geology should be included in the work of the bureau.

The following have served as State Mineralogist: Henry G. Hanks, 1880-1886; William Irelan, 1886-1893; J. J. Crawford, 1893-1897; A. S. Cooper, 1897-1901; Lewis E. Aubury, 1901-1911; Wm. H. Storms, December 1911-February 1913; Fletcher Hamilton, 1913-1923; Lloyd L. Root, February 1923-July 1928; the incumbent since August 1, 1928.

By enactment at the 1927 legislative session, Article IIj was added to the Political Code creating the Department of Natural Resources, and providing for the transfer of the State Mining Bureau to the new department as the ''Division of Mines and Mining.'' This was amended in 1929, changing the name to ''Division of Mines'' and creating a ''State Mining Board'' to consist of five members whose duty it is to determine ''general policies for the guidance of the Division of Mines.'' The organization chart (fig. 1) shows the present-day set-up of the Division, its relation to other divisions of the department, and its cooperation and coordination with other institutions or surveys, Federal, State, and educational.

In addition to the main headquarters with offices in the Ferry Building, San Francisco, including the library, laboratory, and mineral exhibits, district mining engineers are stationed at offices in Sacramento, Los Angeles, and Redding. Reports and bulletins to a total number of more than 185 have been published over the 66 years, describing in detail (with maps, charts, and photographs) the varied mineral substances available in this great commonwealth of California—their location, character, transportation, and other pertinent data. In 1929, by

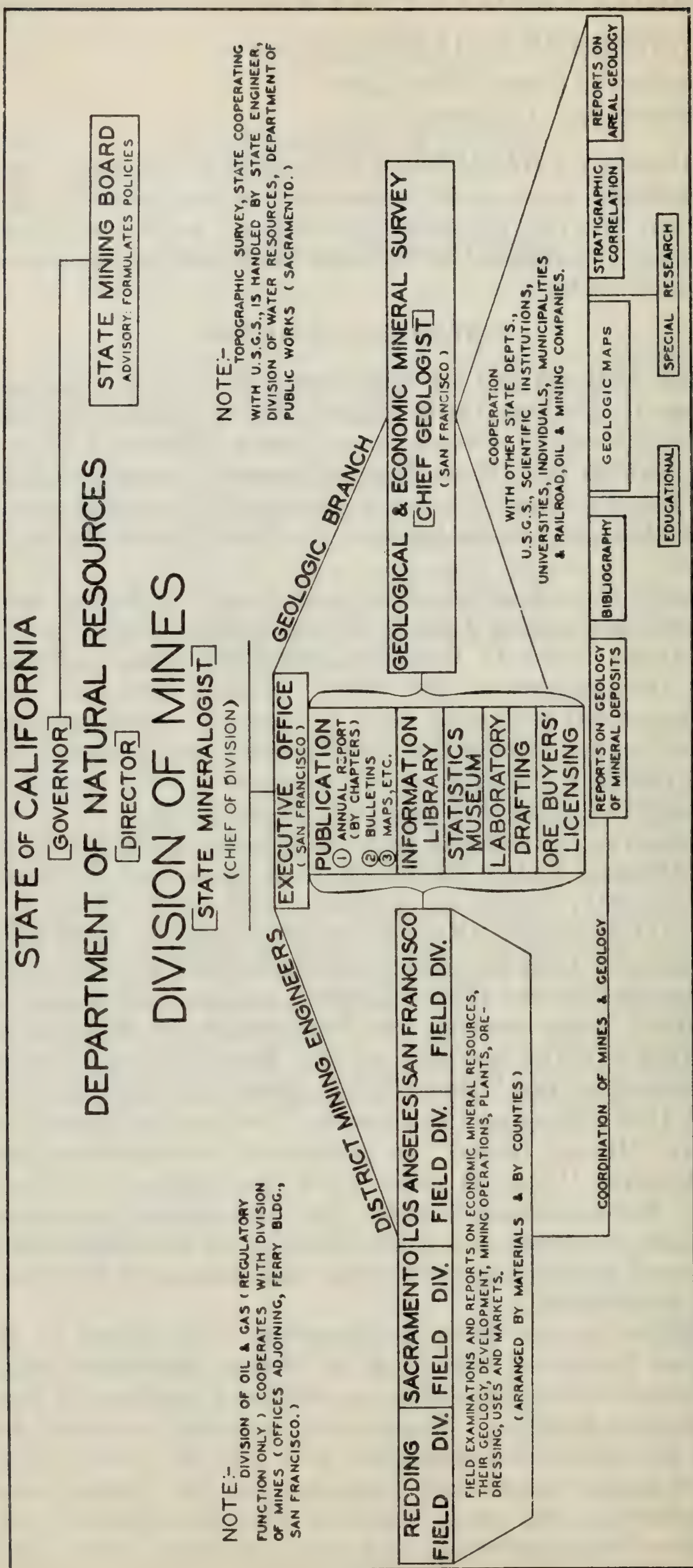


FIG. 1. Chart showing organization and functions of the California State Division of Mines.

appropriation, definite provision was made for geological investigations, reports, and maps. This provision continues, and has become an important feature of the Division's activities.

GENERAL SUMMARY

With reference to our cooperative and coordinated endeavors with other institutions, I am pleased to say that during this past biennium and throughout the period of war activity we continued to have and enjoy the most cordial and appreciated relations with such groups as the United States Geological Survey, United States Bureau of Mines, United States Forest Service, other Federal organizations (specifically the Reconstruction Finance Corporation and its Metals Reserve Company, also War Production Board), the geological and mining engineering departments of the several universities in California (as well as some outside of this State, whose men have done professional work within our borders), also with the operating mining and oil companies throughout California. Shortly after V-J Day, both the Metals Reserve Company and the War Production Board were discontinued. Valuable cooperation also obtains with the California Academy of Sciences, American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, technical magazines, and consulting engineers and geologists. Contributions from these groups have been noteworthy, to the quarterly issues of the State Mineralogist's Report (California Journal of Mines and Geology), to various maps (in particular the Geologic Map of California), and to bulletins issued by the Division, in particular Bulletin 118 (Geologic Formations and Economic Development of the Oil and Gas Fields of California).

California is an extensive empire and has widespread and diversified resources of minerals not excelled by any other equal area on the face of the planet. It is a big task for the small staff of the Division of Mines to adequately cover this large assignment and keep up-to-date on the economic developments in all of the varied industries and areas within our borders. From the beginning of war operations in Europe and especially after December 7, 1941 with the entrance of the United States into the conflict, most of our attention was given to inventorying and developing our domestic resources of "strategic" and "critical" minerals important to the United States in the war program. These included specifically quicksilver, chromite, manganese, tungsten, antimony, piezo-electric quartz, as well as others, of which California had currently active, and still has potential, resources. Printed reports, bulletins, and maps have been made available on quicksilver, petroleum, chromite, tungsten, and manganese, and others on copper, iron, and zinc are either in press or in course of preparation. A list is included elsewhere herein of the papers, bulletins, reports, maps, and other publications issued during this biennial period.

The following figures on the receipts from publication sales for the biennum are of interest:

$7,859.35—July 1, 1944 to June 30, 1945.

$8,332.45—July 1, 1945 to June 30, 1946 (June estimated).

Over-the-counter sales in each of the two years were divided among the three offices of the Division (none are sold at Redding), as follows:

San Francisco—$1234.30 and $1642.75
Los Angeles—$1515.50 and $1616.85
Sacramento—$321.75 and $493.00
Mail orders—San Francisco—$4081.80 and $3718.85
Subscriptions—(Journal of Mines and Geology) $706.00 and $861.00

GEOLOGIC BRANCH

A large number of useful reports have been published during the biennium as a result of cooperation between the Geologic Branch and other geological agencies and institutions. Most of these reports have appeared in the *California Journal of Mines and Geology,* while others have been issued as chapters in Bulletin 129. Several reports are still in press. The subjects cover a large field: descriptive geology, areal geologic mapping, mineralogy, use and development of minerals by the Indians, topographic mapping, war-time mineral industry, iron-ore deposits and reserves, economic geology of quartz-crystals, quicksilver, tungsten, nickel, tin, granite, and chromite. The reports cover various parts of the State, from the Oregon boundary to San Diego, and from the Pacific Coast to east of the Sierra Nevada. Most of the cost to the State of these reports lies in their publication; their sale, however, returns a large part of this cost again to the State. It is a great satisfaction that such splendid technical work has been generously contributed to the program of the Geologic Branch. The contributions have come from university faculty members, graduate students, commercial geologists and engineers, and members of the Federal Geological Survey and Bureau of Mines.

Reports Released by the Geologic Branch During the Biennium July 1, 1944-June 30, 1946

Journals

Miller, William J., Geology of Palm Springs—Blythe strip, Riverside County, California: California Jour. Mines and Geology, vol. 40, no. 1, pp. 11-72, 23 figs., pls. 1-4, January 1944.

Miller, William J., Geology of parts of the Barstow quadrangle, San Bernardino County, California: California Jour. Mines and Geology, vol. 40, no. 1, pp. 73-112, 18 figs., pls. 5-6, January 1944.

Miller, William J., Geology of the Needles—Goffs region, San Bernardino County, California: California Jour. Mines and Geology, vol. 40, no. 1, pp. 113-129, 1 fig., pl. 7, January 1944.

Jenkins, Olaf P., Status of topographic and geologic mapping in California: California Jour. Mines and Geology, vol. 40, no. 2, pp. 171-176, pl. 8, April 1944. (Plate 8 also printed separately with report on back.)

Fiedler, William Morris, Geology of the Jamesburg quadrangle, Monterey County, California: California Jour. Mines and Geology, vol. 40, no. 2, pp. 177-250, 32 figs., pls. 9, 10, April 1944. Accompanied by colored lithograph geologic map of the quadrangle, scale 1:62500.

Murdoch, Joseph, and Webb, Robert W., Progress on revision of Bulletin 113, "Minerals of California": California Jour. Mines and Geology, vol. 40, no. 3, p. 290, July 1944.

Heizer, Robert F., and Treganza, Adan E., Mines and quarries of the Indians of California: California Jour. Mines and Geology, vol. 40, no. 3, pp. 291-359, 11 figs., July 1944.

Rogers, Austin F., Pellet phosphorite from Carmel Valley, Monterey County, California: California Jour. Mines and Geology, vol. 40, no. 4, pp. 411-421, 6 figs., October 1944.

Durrell, Cordell, Geology of the quartz-crystal mines near Mokelumne Hill, Calaveras County, California: California Jour. Mines and Geology, vol. 40, no. 4, pp. 423-433, 3 figs., pls. 11-12, October 1944.

Yates, Robert G., and Hilpert, Lowell S., Quicksilver deposits of central San Benito and northwestern Fresno Counties, California: California Jour. Mines and Geology, vol. 41, no. 1, pp. 11-35, 3 figs., pls. 1-5, January 1945.

Ricker, Spangler, War-time mineral industry of California: California Jour. Mines and Geology, vol. 41, no. 1, pp. 37-44, January 1945.

Averitt, Paul, Quicksilver deposits of the Knoxville district, Napa, Yolo, and Lake Counties, California: California Jour. Mines and Geology, vol. 41, no. 2, pp. 65-89, 2 figs., pls. 6-14, April 1945.

Bateman, Paul C., Pine Creek and Adamson tungsten mines, Inyo County, California: California Jour. Mines and Geology, vol. 41, no. 4, pp. 231-249, 1 fig., pls. 36-47, October 1945.

Helm, Mary H., Index to topographic quadrangles of California, with an introduction by Olaf P. Jenkins: California Jour. Mines and Geology, vol. 41, no. 4, pp. 251-360, 6 figs., October 1945.

Bulletins

BULLETIN 129, *Iron Resources of California*, including:

Hadley, Jarvis B., Iron-ore deposits in the eastern part of the Eagle Mountains, Riverside County, California: California Div. Mines Bull. 129A (preprint), pp. 1-24, 11 figs., pls. 1-3, 1945.

Lamey, Carl A., Iron Mountain iron-ore deposits, Lava Bed district, San Bernardino County, California: California Div. Mines Bull. 129B (preprint), pp. 25-38, figs. 12-15, pl. 4, 1945.

Lamey, Carl A., Iron Mountain and Iron King iron-ore deposits, Silver Lake district, San Bernardino County, California: California Div. Mines Bull. 129C (preprint), pp. 39-58, figs. 16-19, pls. 5-7, 1945.

Lamey, Carl A., Old Dad Mountain iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129D (preprint), pp. 59-67, figs. 20-22, 1945.

Lamey, Carl A., Cave Canyon iron-ore deposits, San Bernardino County, California: California Div. Mines Bull. 129E (preprint), pp. 69-83, figs. 23-29, pl. 8, 1945.

Lamey, Carl A., Vulcan iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129F (preprint), pp. 85-95, figs. 30-33, pl. 9, 1945.

Lamey, Carl A., Iron Hat (Ironclad) iron-ore deposits, San Bernardino County, California: California Div. Mines Bull. 129G (preprint), pp. 97-109, figs. 34-37, pl. 10, 1945.

Lamey, Carl A., Ship Mountains iron-ore deposit, San Bernardino County, California: California Div. Mines Bull. 129H (preprint), pp. 111-116, fig. 38, pls. 11-12, 1945.

Trask, Parker D., and Simons, Frank S., Minarets magnetite deposits of Iron Mountain, Madera County, California: California Div. Mines Bull. 129I (preprint), pp. 117-128, figs. 39-43, pl. 13, 1945.

Lamey, Carl A., Hirz Mountain iron-ore deposits, Shasta County, California: California Div. Mines Bull. 129J (preprint), 129-136, fig. 44, pls. 14-16, 1945.

Reports in Press Near End of 1944-1946 Biennium (May 1946)

Journals

Wright, Lawrence B., Geology of Santa Rosa Mountain area, Riverside County, California: California Jour. Mines and Geology, vol. 42, no. 1, 2 figs., pls. 1, 1A-1D, January 1946.

Creasey, S. C., Geology and nickel mineralization of the Julian-Cuyamaca area, San Diego County, California: California Jour. Mines and Geology, vol. 42, no. 1, 2 figs., pls. 2-4, January 1946.

Wiese, John H., and Page, Lincoln R., Tin deposits of the Gorman district, Kern County, California: California Jour. Mines and Geology, vol. 42, no. 1, 4 figs., pls. 5-7, January 1946.

Eckel, Edwin B., and Myers, W. B., Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California: California Jour. Mines and Geology, vol. 42, no. 2, 9 figs., pls. 8-20, April 1946.

Everhart, Donald L., Quicksilver deposits at the Sulphur Bank mine, Lake County, California: California Jour. Mines and Geology, vol. 42, no. 2, 8 figs., pls. 21-22, April 1946.

Murdoch, Joseph, Progress on revision of Bulletin 113, "Minerals of California," with notes on some new occurrences: California Jour. Mines and Geology, vol. 42, no. 3, July 1946.

Bailey, Edgar H., Quicksilver deposits of the western Mayacmas district, Sonoma County, California: California Jour. Mines and Geology, vol. 42, no. 3, 3 figs., pls. 29-33, July 1946.

Yates, Robert G., and Hilpert, Lowell S., Quicksilver deposits of Eastern Mayacmas district, Lake and Napa Counties, California: California Jour. Mines and Geology, vol. 42, no. 3, 8 figs., pls. 34-48, July 1946.

Bulletins

BULLETIN 133, *Geology of San Juan Bautista Quadrangle,* including:

Allen, John Eliot, Geology of the San Juan Bautista quadrangle, California: California Div. Mines Bull. 133, 8 pls., 10 figs., 1946.

Fowle, Royal E., Operations of the Granite Rock Company quarry and plant at Logan, San Benito County: California Div. Mines Bull. 133, pls. 9-12, 1946.

BULLETIN 134, *Chromite Deposits of California,* including:

Wells, Francis G., Chromite deposits of Del Norte County, California: California Div. Mines Bull. 134, pt. I, chap. A., 1946.

Dow, D. H., and Thayer, T. P., Chromite deposits of the northern Coast Ranges of California: California Div. Mines Bull. 134, pt. II, chap. 1, 1946.

LABORATORY

Our Mineral Technologist, George L. Gary, reports that the laboratory of the Division headquarters has identified and classified approximately 15,000 samples, mailed or brought into the Division, during the biennium. A written or verbal report is given on each sample and commercial possibilities, if any, are noted. These reports are further supplemented by articles concerning the ore mineral in question.

Samples were received from all of California's 58 counties, mainly from the southern part of the State. Due to the war requirements for most of the biennium 80 percent of the requests accompanying the samples were for strategic minerals such as quicksilver, chromite, tungsten, manganese, antimony, copper, lead, zinc, mica, quartz crystals, aluminum, and magnesium. Approximately 20 percent of California's 70-odd commercial minerals were vitally needed by the war industries and fully 10 percent of the samples examined had commercial possibilities. This information was made available to the public through our files and *Monthly Commercial Mineral Notes.*

The most important contribution that the laboratory has made in the past biennium has been the complete revision of the papers upon the commercial minerals of California. These papers, approximately 60 in all, were prepared and revised by W. B. Winston under the direction of the Mineral Technologist. In April 1941 the first papers of this series were mimeographed. They were originally run off in lots of 500 to 1500, depending upon the importance of the subject. Several of the papers on strategic or critical minerals have been rerun 10 to 15 times as new material was found and the public demand for them increased.

These papers have also been found to be beneficial in other departments of the Division of Mines in answering questions addressed to them by the public either in person or by mail. This was especially true in the Library, Statistical, and Engineering Departments.

These papers are distributed through the main office of the Division of Mines and our regional offices at Los Angeles, Sacramento, and Redding. They are available for reference at many of the public libraries and universities of the Western States, as are our other publications. Certain of these papers have been reprinted by technical journals, magazines, and newspapers. We have been much interested to note that other States as well as the Federal Government have used this method and in some cases a similar format to ours in presenting information of like nature.

These papers are issued in parts or in a complete series as a loose-leaf bulletin. This bulletin No. 124 of the Division of Mines is so arranged that it may be revised and expanded as marketing conditions change and it is the intention of the laboratory, as these changes occur to supplement this bulletin with additional up-to-the-minute information on the properties, occurrences, preparation, uses, tests, markets, and possible buyers, with selected bibliographic references concerning these commercial minerals.

The work being done by the laboratory to train men to prospect for commercial minerals is being continued by Mr. Gary at the San Ramon Valley Union High School at Danville, in Contra Costa County. This program has been under way for 4 years and the results have been very encouraging. The students are of the executive type, holding responsible jobs, or owning their own businesses; and the attendance has been remarkable in view of the demands made upon their time due to the war and reconversion. This class was designed and operated as a potential reservoir of manpower that could be used in field or plant duty by the mineral industry, and it has proved its worth by furnishing men for these purposes.

Field trips have been made by the class to new or operating properties with the idea of securing new production or increasing old production and it is with considerable pleasure that the Division of Mines can point to many letters in its files attesting and confirming the success of this program. This class, sponsored by the Division of Mines, has been instrumental in keeping ore bins full and adding to stock piles of strategic minerals during the war. The importance of continuing this work is becoming more and more evident every day, so that reconversion from war to peace may be effectually carried out. The importance of the mining industry and its relation to the economic welfare of the nation is recognized by our people as never before.

The class of instruction in mineralogy is divided into four parts. The first consists of blackboard lectures on the identification of rocks and the origin, occurrence, and association of minerals; the second consists of the identification of strategic and commercial minerals; the third consists of the chemical examination of minerals and the general principles of chemistry as applied to minerals; the fourth consists of field trips to various parts of the State where commercial minerals are found, and brings the student in contact with actual operations. The class has advanced to where, for the last two years, the members are able to do satisfactory work on the overflow samples of the laboratory. This is of course checked by our Mineral Technologist, before the reports are sent out. The men engaged in this work devote 3½ hours of their time each night, four nights a week, and average 24 Saturdays

and Sundays in the field each year to aid the mining industry of the State.

The laboratory needs and should have traveling field equipment to aid the prospector and small mine operator, for they are the ones that founded the mining industry in California. There is a demand, which can be readily shown, for this service and the State should supply that demand. Moreover, it should be initiated by the State through the Division of Mines, but up to now appropriations for this service have been denied. The small cost involved would be insignificant to the amount of revenue returned to the State by new mining operations which could be developed with this aid.

ORE BUYERS' INSPECTION

The War Production Board's Order L-208, from its promulgation October 8, 1942 to its release July 1, 1945 kept the gold mines of the entire mining west, with a few specific exceptions, almost completely shut down. Small mines with less than seven men employed, hydraulic mines and dredges with limited crews of men over 45 years of age, were permitted to continue. Also, limited crews were allowed the deeper, lode-gold mines for maintenance purposes.

During the period under review the following numbers of gold-buyers' licenses have been issued:

Year	*Limited (@ $2.00)*	*Unlimited (@ $15.00)*
1945	45	47 (Including 8 banks)
1946	44	46 (Including 8 banks)

These figures compare with 66 Limited and 45 Unlimited licenses for the year 1942. "Limited" licenses allow purchases to a total of $1000 per calendar year; and "Unlimited" licenses allow over $1000 in total purchases annually. Our ore buyers' inspector, John F. Bongard, returned February 8, 1945 from war service with the Seabees of the U. S. Navy. He advises that gold mining is beginning to pick up, but slowly. There have been a few minor instances of "highgrading." There has been considerable inquiry for information on the possibilities of small-scale placer mining; and the Division has prepared and made available a mimeographed pamphlet on the subject. We try to discourage such operations, as the returns today are meager. The chances are even more meager than they were in the depression days of 1932-1934.

PUBLICATIONS ISSUED DURING THE BIENNIUM JULY 1, 1944-JUNE 30, 1946

State Mineralogist's Report XL, July and October 1944 chapters (*California Journal of Mines and Geology*). Among the more important subjects are:

Progress on Revision of Bulletin 113, "Minerals of California."
Mines and Quarries of the Indians of California.
Fluorescent Minerals in the Exhibit of the State Division of Mines.
California Mineral Production for 1943.
Biennial Report of the State Mineralogist.
Pellet Phosphorite from Carmel Valley, Monterey County.
Geology of the Quartz-Crystal Mines near Mokelumne Hill, Calaveras County.
Total Recorded Value of Mineral Production in California.

Special Articles:

Strategic Mica.
Marketing Vermiculite.
An Act Providing for the Suspension of Certain Requirements Relating to Work on Tunnel Sites.
An Act Regulating Mineral, Oil and Gas Brokers and Salesmen.

State Mineralogist's Report XLI, 1945. Among the more important subjects included are:

Quicksilver Deposits of Central San Benito and Northwestern Fresno Counties.
War-Time Mineral Industry of California.
Review of California Mineral Production for 1944.
Additions to Bulletin 113.
Quicksilver Deposits of the Knoxville District, Napa, Yolo, and Lake Counties.
Mineral Resources of Riverside County, with Map.
Pine Creek and Adamson Tungsten Mines, Inyo County, with Maps.
Index to Topographic Quadrangles of California.

Special Articles:

Unexpected Use Transforms Outlook for Quicksilver.
Steel.
Recent Legislation Affecting Mining.
Flow-Sheet of American Potash and Chemical Corporation at Searles Lake.

State Mineralogist's Report XLII, January and April 1946 chapters (*California Journal of Mines and Geology*). Among the more important subjects included are:

Geology of Santa Rosa Peak Area, Riverside County.
Geology and Nickel Mineralization of the Julian-Cuyamaca Area, San Diego County.
Tin Deposits of the Gorman District, Kern County.
Quicksilver Deposits of the New Idria District, San Benito County.
Quicksilver Deposits of the Sulphur Bank Mine, Lake County.

Special Articles on:

California's Minerals for Tomorrow.
Relocation of Claim by Original Locator. Decision by State of California, District Court of Appeal.

BULLETIN 128. *California Mineral Production and Directory of Mineral Producers for 1943*, by Henry H. Symons, 222 pages, 10 illustrations. Gives detailed figures of commercial production of all mineral substances in California for the calendar year, 1943, segregated by substances and by counties of origin.

BULLETIN 129. *Iron Resources of California* Preprints of Parts A to J, inclusive, a total thus far of 136 pages, with sections and geologic maps, and covering the following deposits: *Eastern Part of the Eagle Mountains, Riverside County; Iron Mountain, Lava Bed District, San Bernardino County; Iron Mountain and Iron King, Silver Lake District, San Bernardino County; Old Dad Mountain, San Bernardino County; Cave Canyon, San Bernardino County; Vulcan, San Bernardino County; Iron Hat (Ironclad), San Bernardino County; Ship Mountains, San Bernardino County; Minarets Magnetite, of Iron Mountain, Madera County; Hirz Mountain, Shasta County.* The authors are: Jarvis B. Hadley, Carl A. Lamey, Parker D. Trask, Frank S. Simons, of the U. S. Geological Survey. There are several other reports yet to be included in this series, and when all are completed, they will be bound in a single volume. Meanwhile a limited number of the *preprints* are available for distribution.

BULLETIN 130. *Economic Mineral Resources and Production of California. A Survey with Reference to Post-War Employment*, by Samuel H. Dolbear, and the following contributing authors: H. Foster Bain, Walter W. Bradley, Hadley R. Bramel, S. R. Coghlan, G. A. Joslin, Robert M. Searls, J. Clark Sutherland, Roy E. Tremoureux, Herbert Waterman; 459 pages, 18 illustrations, 2 maps. Also contains a Directory of Producers, and a series of Tables of Total Recorded Mineral Production for the 58 counties of California. This report was financed through an appropriation made at the 1944, Fourth Extra Session, to the State Reconstruction and Reemployment Commission. The survey was conducted under supervision of the State Mineralogist.

BULLETIN 131. *Consolidated Index of Publications, 1880-1943 (inc.)*, of the State Mining Bureau and Division of Mines, In Press.

BULLETIN 132. *California Mineral Production and Directory of Mineral Producers, for 1944*, by Henry H. Symons, 224 pages, 8 illustrations. Gives detailed figures of commercial production of all mineral substances in California for the calendar year 1944.

CONCLUSION

The undersigned, after nearly 35 years service on the staff of this Division (and its predecessor, the State Mining Bureau) has filed application for retirement effective August 1st, which will complete 18 years as State Mineralogist or Chief of the Division. He has seen the staff and the activities of the bureau grow in numbers and effectiveness, also in the esteem and support of the mineral industries of our outstanding Commonwealth. These for the writer, have been years of most interesting endeavor and activity, of many lasting and sincere friendships made. I feel that it is time to "hand over the torch" to a younger man.

The 1945 regular session of the Legislature, recognizing the effectiveness, value, and importance of the Division's work to the State's economy as was indicated by the strong support and recommendations of the industry, gave substantial increases in the appropriation allotments for the current biennium. We trust, and recommend, that the same strong support will be accorded my successor in office. California is an empire in its large area and great diversity of mineral resources. Their development and utilization can be highly enhanced by an alive and well-financed Division of Mines.

Respectfully submitted.

WALTER W. BRADLEY
State Mineralogist

July 1, 1946.

REDDING FIELD DISTRICT

MINES AND MINING IN TEHAMA COUNTY, CALIFORNIA

By J. C. O'Brien *

OUTLINE OF REPORT

INTRODUCTION

Tehama County is situated in the upper Sacramento Valley in the north-central portion of the State. It extends approximately 50 miles from east to west and 40 miles from north to south and has a land area of 1,872,000 acres. There is an average annual rainfall of 26 inches and the temperature averages 78.4 degrees in summer and 47.1 degrees in winter. Elevations range from 300 feet in the Sacramento Valley to over 6000 feet in the Sierra Nevada and Klamath Mountains, which form the east and west boundaries of the county.

The lowlands along the Sacramento River and its tributaries support many thousands of acres of fruit orchards, and the agriculture and livestock business has a value of more than $3,500,000 per year.

Red Bluff, the county seat, is situated about the center of the county on the Sacramento River and was once the head of navigation. It is on the main line of the Southern Pacific Railroad 138 miles north of Sacramento. U. S. highway 99 E and 99 W join at Red Bluff and continue north. U. S. highway 36, the Susanville-Reno road, starts from Red Bluff. Two secondary highways cross the county to the west, and numerous graveled roads extend east and west to the foothills of the mountains. Red Bluff is an intermediate stop on the Seattle-San Diego route of United Airlines.

The 1940 census reported a population of 14,316 for Tehama County.

GEOLOGY

The eastern part of Tehama County is covered with a succession of lava flows. They range from Pliocene basalt to Recent andesite and rhyolite flows from Mount Lassen and other volcanic vents in the Cascade Mountains. Marine sediments of Carboniferous and Cretaceous ages are exposed beneath the lavas in the canyons of the creeks flowing

* District Mining Engineer, Redding District, California State Division of Mines. Manuscript submitted for publication February 25, 1946.

Mineral Production of

Year	Gold, value	Chromite		Brick	
		Tons	Value	M	Value
1880-1884	$22,000				
1894		1,680	$12,680		
1895		950	9,025	500	$2,500
1896		56	475		
1897					
1898				200	1,400
1899				300	1,800
1900				325	2,200
1901				300	2,000
1902				500	3,500
1903				600	4,500
1904				500	3,500
1905				650	5,000
1906				700	5,600
1907				400	3,200
1908				400	3,000
1909					
1910				600	3,600
1911					
1912				225	1,300
1913				300	1,800
1914					
1915		[2]		400	2,700
1916		1,896	39,702	[2]	
1917		2,053	41,646		
1918		3,261	152,291		
1919		[2]			
1920					
1921					
1922				[2]	
1923					
1924		[2]		[2]	
1925				[2]	
1926		[2]		[2]	
1927					
1928					
1929		[2]			
1930				[2]	
1931					
1932				[2]	
1933					
1934	1,146				
1935	177				
1936					
1937					
1938	[2]				
1939	31,675				
1940					
1941					
1942		[2]			
1943		[2]			
1944		[2]			
Totals	[2]$54,998	[2]9,896	$255,819	[2]6,800	$47,600

Grand total value, $1,669,700.

[1] Includes crushed rock, rubble, sand, gravel.

[2] See under 'Unapportioned.'

Tehama County, 1880-1944

Mineral water		Salt, value	Miscellaneous stone,[1] value	Miscellaneous and unapportioned		
Gallons	Value			Amount	Value	Substance
10,000	$2,400					
54,000	8,000					
10,000	18,000					
20,000	4,000					
5,000	2,500					
8,000	4,000					
8,000	4,000					
550,000	55,000					
20,000	2,000	$300				
5,000	500	300				
5,000	500	300				
5,000	500					
75	42		$600			
100	100	200				
1,000	500	[2]	750		$752	Chromite and salt.
[2]			11,076		3,575	Brick, granite, mineral water, natural gas.
			2,373			
			2,500		2,800	Other minerals.
			7,500		1,500	Other minerals.
			[2]		26,400	Unapportioned.
			30,520		300	Other minerals.
			[2]		9,388	Brick, miscellaneous stone.
			4,900		1,316	Other minerals.
			26,054		8,400	Brick, chromite.
			[2]		77,183	Brick, miscellaneous stone
			2,100		8,240	Brick, chromite.
			4,450		900	Other minerals.
			11,945		2,444	Other minerals.
			9,956		4,524	Chromite and sandstone.
			218,300		8,100	Brick and sandstone.
			49,407		1,000	Other minerals.
			11,887		2,500	Brick and sandstone.
			30,309		25	Other minerals.
			38,427	3 ozs.	2	Silver.
			11,214			
			100,403			
			65,193			
			[2]		81,431	Gold, platinum, silver, miscellaneous stone.
			44,956		46 5,417	Silver. Other minerals.
			51,880			
			2,925			
			[2]		47,533	Chromite, miscellaneous stone.
			[2]		72,917	Chromite, miscellaneous stone.
			[2]		101,823	Chromite, miscellaneous stone.
[2]701,175	$102,042	[2]$1,100	[2]$739,625		$478,516	

westward from the mountains. Non-marine sediments ranging from Pliocene to Recent extend some 20 miles east and west from the Sacramento River. The western half of the county is covered with thick beds of Cretaceous and Jurassic marine sediments which have been strongly folded and faulted in the Klamath Mountains, which form the western border of the county. A serpentine belt about 1¼ miles wide strikes northwestward along the eastern slope of the Coast Ranges, and is flanked on the west by schists and other metamorphic rocks.

MINING

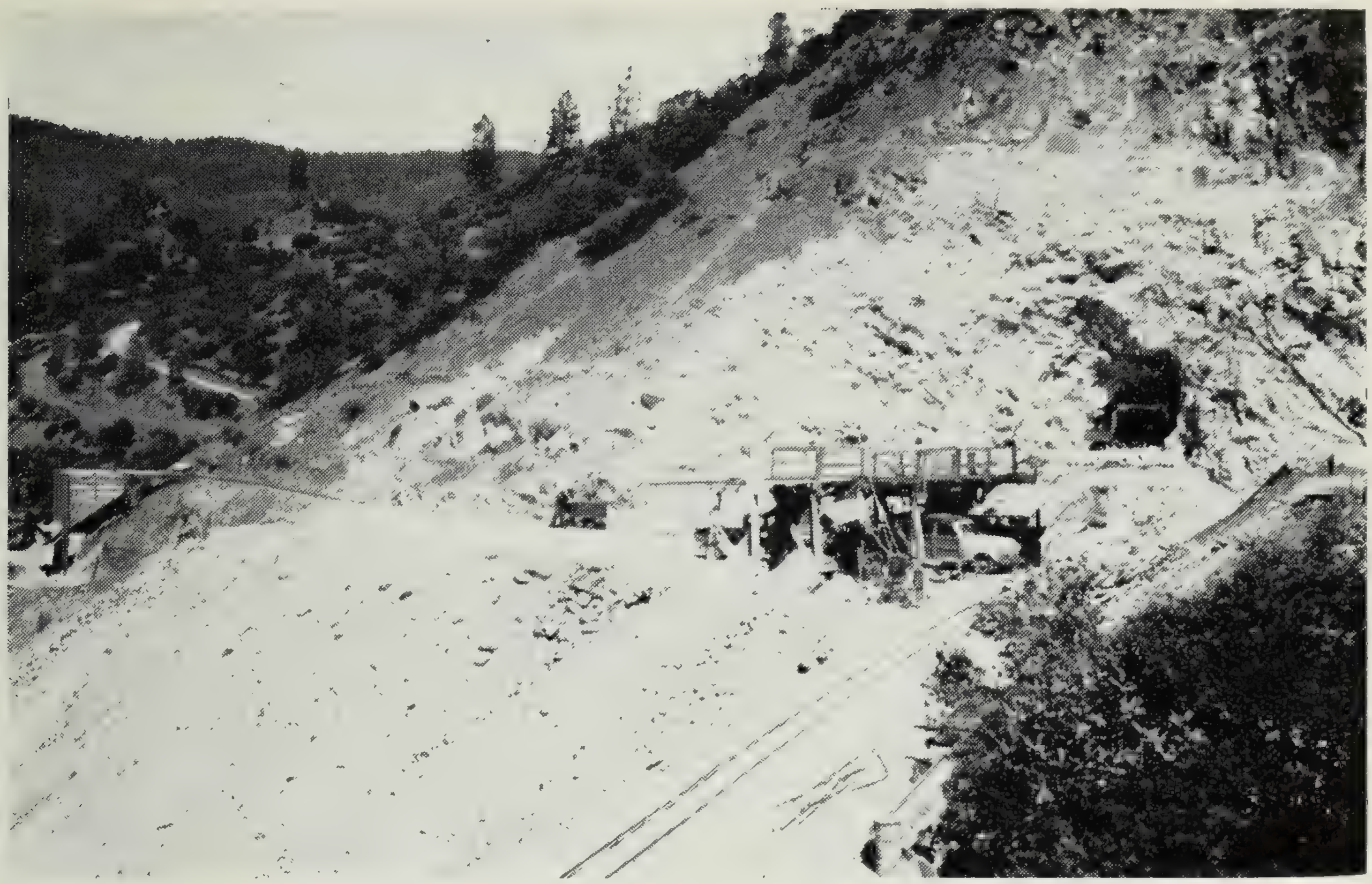
Mining has been a minor industry in Tehama County, and the total mineral production, 1880-1944 is only $1,669,700. Except for the production of chromite and sand and gravel there has been very little mining activity in recent years. Since the last report on the mines and mineral resources of Tehama County issued in 1928, there has been quite a little activity in oil and gas leases, and several wells have been drilled. A well drilled about 2 miles northeast of Corning in 1943 was reported to have flowed up to 17 million cu. ft. of gas from zones 1070-1504 feet in depth. No commercial use of this gas has been made to date. Properties and activities described in earlier Reports of the State Mineralogist, now out of print, are included in this report to summarize the industry as a whole.

Chromite

Chromite occurs in the serpentine belt which strikes northwestward along the east slope of the Coast Ranges about 35 miles west of Red Bluff. It occurs both in stringers and in lenses of high-grade ore and finely disseminated through serpentine and dunite. The earliest record of production was in 1886, when the Tehama Consolidated chrome mine located deposits in sec. 16, T. 25 N., R. 7 W. and mined high-grade lenses from open cuts. Shipments were made by rail to San Francisco and then by boat to Philadelphia. Hensley and Hazelwood were reported to be working a deposit by open cut in secs. 13 and 14, T. 26 N., R 7 W. in 1890. Intermittent shipments totaling over 5000 long tons were reported to 1899, when the properties were closed and remained idle until the first world war demand in 1915.

Many claims were located for chromite during the first world war, and about 8000 tons of a minimum 40 percent Cr_2O_3 were produced from 1915-18. Practically all production ceased with the abrupt drop in the price for chromite at the armistice in 1918, and the deposits were idle until the Metals Reserve Company established specifications, prices, and stockpiles for small lots of domestic ores in 1942. The principal production to date has come from deposits on patented land in secs. 16, 17, 20 and 22, T. 25 N., R. 7 W. Although most of the production came from high-grade stringers and lenses in serpentine, some high-grade concentrates were produced in 1918 from the disseminated ores on the Kleinsorge property in sec. 27, T. 25 N. R. 7 W., and by the Hillside Mining Company in sec. 16, T. 25 N., R. 7 W. A large tonnage of this type ore estimated to contain 10 percent Cr_2O_3 remains in the area.

Although many of the old chromite deposits were re-examined and prospected after 1942, practically all of the recent production has come from a deposit in sec. 17, T. 25 N., R. 7 W., leased and operated by McLaughlin and Applegarth.



A, McLAUGHLIN AND APPLEGARTH CHROMITE DEPOSITS
Grau pit, sec. 17, T. 25 N., R. 7 W.
Photo by Walter W. Bradley

B, McLAUGHLIN AND APPLEGARTH CHROMITE DEPOSITS
Grau pit, upper level. Face is massive chromite
Photo by Walter W. Bradley

A, McLAUGHLIN AND APPLEGARTH CHROMITE DEPOSITS
Grau pit, lower level. Face is massive chromite
Photo by Walter W. Bradley

B, McLAUGHLIN AND APPLEGARTH CHROMITE DEPOSITS
Banded chromite in serpentine, sec. 16, T. 25 N., R. 7 W. North Fork of Elder Creek
Photo by Walter W. Bradley

McLaughlin and Applegarth Deposits. McLaughlin and Applegarth, 3001 Russ Building, San Francisco 4, California, leased secs. 9, 17, 21, and a portion of the SW¼ sec. 15, T. 25 N., R. 7 W. from the Grau estate and Wm. E. Kleinsorge, and sec. 16, T. 25 N., R. 7 W. from the State in November 1941. They built about 3 miles of road south from the Forest Service road and west along the north fork of Elder Creek to sec. 17. Chromite was mined from an open cut excavated for some 75 feet to the north into the hill, which slopes about 30° south. The excavation was about 90 feet wide, and the face of the cut about 40 feet high. The east side of the pit bordered against a reddish-brown dunite. Chromite occurred in lenses and pockets in a serpentine which had been leached and altered to a soft talcose material. Irregular lenses of high-grade ore had a N. 60° W. strike and about a 30° E. dip.

Pockets ranging in size from a few tons to over a hundred tons were mined from the open pit and from an adit run from the pit floor northeastward into the hill. The adit and side sets from which the chrome was mined were timbered with square sets. A crosscut adit 75 feet lower and a raise to the pit adit failed to find any ore. Rock was drilled with mounted air drills and jackhammers. Chromite was sorted from the broken rock, loaded and trammed in mine cars to a 50-ton bin, from which it was hauled by truck 35 miles to Red Bluff. Shipments were made on contract to Sacramento and to the Metals Reserve stockpile at Anderson. Several thousand tons of ore shipped from the property is said to have averaged 43 percent Cr_2O_3.

A camp and boarding house was maintained for a crew which varied from 5 to 12 men.

Moore and Robinson Deposits. H. T. Moore and H. A. Robinson of Platine shipped some high-grade chromite to the stockpile at Anderson from secs. 11 and 12, T. 28 N., R. 10 W. The ore occurred in small lenses and pockets in a soft talcose serpentine and was mined from shallow pits and trenches. Production from this area was handicapped because the ore had to be packed about 2 miles down the mountain to where it could be loaded on trucks. This property is sometimes called the Beegum chromite mine and was formerly owned by the Western Rock Products Company and the Seagrave chrome mine. Shipments were made to the Metals Reserve Company stockpile at Anderson in 1945.

Big Bear Chrome Mine. The Big Bear mine is in sec. 20, T. 25 N., R. 7 W., and is owned by Liston Ehorn of Red Bluff. A few tons of high-grade float ore were shipped to the Anderson stockpile from this property in 1943.

Kleinsorge Mine. Located in sec. 27, T. 25 N., R. 7 W., the Kleinsorge mine is on patented land owned by Wm. E. Kleinsorge of Sacramento. Chrome ore was discovered on this section in 1916, and some 700 tons of 42 percent Cr_2O_3 were mined in 1917 from high-grade lenses in a talcose serpentine. A very large tonnage of an estimated 6 percent disseminated-type ore was developd in five open pits, and a mill was built and operated in 1918. The ore was transported to the mill by aerial trams, and mine cars. Material that passed over a 1½-inch spaced rail grizzly was crushed in a 6- by 8-inch jaw crusher. Ore under 1½-inch size was crushed by ten 1150-pound stamps and concentrated by four 5- by 12-

foot Wilfley tables. Power was furnished by a 36-inch Pelton wheel when sufficient water was available from the middle fork of Elder Creek. A 60-horsepower 2-cylinder Sampson gasoline engine was used when the water was low. A 7½-kilowatt Westinghouse D. C. generator powered by an 18-inch Joshua Hendy water wheel furnished lights.

About 40 tons of ore was milled in 24 hours and produced 7 tons of concentrates of 50 percent Cr_2O_3. Twenty-two carloads of concentrates were reported shipped in 1918.

The mine and mill buildings and equipment were in a wrecked condition in 1942, and the old pits had caved, so the property was not reopened.

Bibl.: B. 76, p. 206. Rept. XXIV, p. 212 (1928); U.S.G.S. B. 725, p. 2-4.

Noble Electric Steel Company Deposits. The Noble Electric Steel Company purchased chromite deposits in sec. 16, T. 25 N., R. 7 W. from J. A. Heslewood in November 1915 and built a wagon road up the north fork of Elder Creek to them.

Chromite occurred in irregular lenses and bands of high-grade ore in soft talcose serpentine, and as low-grade disseminated ore in dunite. It was mined by wide open cuts until the overburden became too great and then by short adits and shallow shafts. Some 3200 tons of 47 percent Cr_2O_3 were mined from this property by the Noble Electric Steel Company in 1916-17 and shipped to their electric steel furnaces at Heroult in Shasta County.

In 1928, Savage Brothers of Red Bluff obtained a lease on sec. 16 from the State and built a small concentrating plant consisting of a Lane mill and two tables. Mr. S. D. Furber of Corning reported that by grinding to 60 mesh they were able to make a 64 percent Cr_2O_3 concentrate from the disseminated-type ore. Shipments of 75 tons were made to the Columbia Steel Company, Pittsburg, California, and were said to have been added directly to the molten steel. When the U. S. Steel Corporation took over the Columbia Steel Company plant, purchase of concentrates was stopped, and the mining and milling operations were closed down.

McLaughlin and Applegarth leased sec. 16 in 1941 but the old pits, adits and shafts were filled with slides and no new ore was mined. The road to the property is now closed by slides.

Chromite was first mined from deposits in sec. 16 by the Tehama Consolidated Chrome Company in 1886, and a total of 4500 tons of 47 percent Cr_2O_3 was shipped up to 1895. They were followed by a succession of operators, and the property has been described as the Heslewood and Crumbo, M. J. Cheatham, Elder Creek, S. W. Hill, Hillside, Lowry, Savage Brothers, and the State mine in Reports of the State Mineralogist.

Bibl.: X, p. 692; XII, p. 38; XIII, p. 50; XXIV, p. 212; XXXVII, p. 132; B. 38, p. 275; B. 76, pp. 206, 207; U.S.G.S. B. 725, pp. 2-4.

The lack of access roads again discouraged development of old deposits such as the Basler in secs. 4 and 8, T. 25 N., R. 7 W. (XV, p. 259), the Tedoc, in secs. 21 and 28, T. 28 N., R. 9 W. (B. 76, pp. 220, 224) and the Toms Head, in sec. 36, T. 27 N., R. 9 W. (B. 76, p. 209).

Clay

Excavations and wells in the Sacramento River bottom lands show that there are beds of yellow and white clay of varying thicknesses (4 to 160 feet) beneath the surface soil and gravels.

O'Connor Brothers of Red Bluff manufactured brick from a clay deposit 8 to 11 feet thick in sec. 29, T. 27 N., R. 3 W., for several years prior to 1932. The plant has been dismantled, and no deposits have been worked for clay in recent years.

Bibl.: R. XXIV, p. 212; R. XV, p. 260.

Copper

Some claims have been located on copper prospects in the serpentine belt which strikes northwest along the eastern slope of the mountains about 35 miles west of Red Bluff. What little development work was done on the claims was discouraging and most of the locations have now been abandoned. The California and Massachusetts Copper Mines are described on p. 261 of the 15th Report of the State Mineralogist (1916) as follows:

"*California and Massachusetts Copper Mines.* The California and Massachusetts properties are in sec. 25, T. 27 N., R. 9 W. and are situated on the north slope of Tom Head Mountain, about 40 miles west of Red Bluff.

"The holdings consist of three claims, namely: Sulphide, Uncle Sam, and Spring. The deposit occurs in the form of a vein striking N. 75° W. and dipping 65° N. in diabase. This vein is capped on the surface by iron gossan. The ore is chalcopyrite, associated with pyrite. Developments consist of two tunnels, at an elevation of 4150 feet; a crosscut tunnel has been driven south into the mountain 420 feet, cutting the vein at a distance of 150 feet from the portal, then drifts run east and west for a distance of 200 feet.

"The width of ore developed on this level was about 5 feet. Several winzes have been sunk from this level on the vein to depths of 30 feet. About 150 feet above this tunnel there is another tunnel 366 feet long, which intersected the vein at 66 feet south of portal, with drifts east 150 feet and west 100 feet on the vein. The ore developed on this level varies in width from 4 to 20 feet. The ore so far developed has a very low copper content. The equipment on the property consists of an 80-horse power boiler, 12- by 14- by 14-inch Sullivan air compressor, cars and track, with tool and blacksmith shops. Idle. California and Massachusetts Copper Mines Co., owner, William Wrigley, Jr., president; J. C. Cox, secretary, Kestner Bldg., Chicago, Ill."

Basler Mine. The Basler mine, or White Bluff group, is in sec. 4, T. 25 N., R. 7 W., and is reported to have made a shipment of native copper float to a smelter in Germany; but an 800-foot crosscut was discontinued when it hit some fault-breccia material cemented with sulphides of iron and a small amount of chalcopyrite.

Other copper prospects are described in Division of Mines Bulletin 50 (1908), pages 157 and 158, as follows:

"*Elder Creek Groups.* In section 20, township 25 north, range 7 west, and in sections 9, 10, 15, and 16, township 24 north, range 7 west; comprise three claims owned by W. Richards, five claims belonging to F. T. Notz, three claims to A. Henley, and three claims to George W. Cooper. All show some copper indications.

"L. E. Perine worked on copper stringers in section 25, township 27 north, range 8 west."

"*Kestner & Thompson* prospected a claim in section 4, township 27 north, range 7 west. They have three tunnels. The vein, 4 to 5 feet in width, is in serpentine."

"*Tom Head.*—In section 31, township 27 north, range 8 west, 5-foot vein in greenstone, course northwest-southeast; dip slightly northeast, containing carbonate ore; development, open cut and 30-foot tunnel.

"*Uncle Sam.*—In section 25, township 27 north, range 8 west, 24-foot vein; strike, northwest-southeast, between lime foot and greenstone hanging wall. Ore, sulphides and some native copper. Three tunnels of 60, 300, and 114 feet, with 200-foot drifts.

"*The Halley.*—In section 5, township 26 north, range 9 west, and

"*Verde.*—In section 24, township 27 north, range 9 west, are in slate and lime. Undeveloped."

Gold

The gravels of the Sacramento River north of Red Bluff and of Cottonwood Creek have yielded practically all of the reported $55,000 in gold credited to Tehama County. The Chinese ground-sluiced gravel near Jelly Ferry, 12 miles north of Red Bluff, in the early days, and they were followed by an early dredge, which failed because it could not recover the fine gold. Dredges operating in 1938 and 1939 worked only selected lengths of the river bed where the pay streak was confined to a 10- to 12-foot bed of gravel. They did not dig to bedrock. Gold quartz veins discovered in the mountains west of Paskenta and in the vicinity of Toms Head Mountain had little development work done on them and they have all been idle or abandoned in recent years.

The Fifteenth Report of the State Mineralogist (1916), page 261, describes the *Bowers Creek mine* as

> "A prospect 10 miles west of Paskenta, situated on the east slope of Beauty View Butte, sec. 20, T. 23 N., R. 7 W. The vein strikes N. 50° W. and dips 60° into the diabase. A tunnel has been driven 30 feet on the vein, which averages 18 inches in width. Idle. D. P. Thurston, E. P. Logan et al., of Paskenta, owners."

The Twenty-fourth Report of the State Mineralogist (1928), page 213, states,

> "*Joe Arnol prospect,* Joe Arnol of Manton is sinking a prospect shaft for gold on section 28, T. 30 N., R. 1 E., one mile south of Manton. He states that he drilled a six-inch hole which penetrated the basaltic lava at a depth of 32 feet and entered gravel which continued to a depth of 50 feet. A sample of this gravel, which he sent to a San Francisco assayer, was said to contain $13.50 per ton in gold. At the time of the visit to the prospect the shaft was down 30 feet in closely packed bowlders of vesicular basaltic rock."

Several lode locations in the Beegum district were recorded in 1926 and 1927 but very little development work was done and they have since been abandoned.

Midland Company operated a dragline dredge at Big Bend, sec. 29, T. 28 N., R. 3 W., in 1938-39. F. A. Hoyer was superintendent. The outfit included a Thew-Lorain 55-foot boom dragline, powered by a Caterpillar D-13000. They dug 10 to 12 feet deep with a 1½-yard bucket, but did not get to bed rock. The washing plant was floated on four 10 by 30 by 3½-foot wooden pontoons. The trommel was 4 by 30 feet and had 23 feet of screen with holes ⅜- to ½-inch. The stacker belt was 26 inches wide and 45 feet long. The gold was recovered in 540 square feet of expanded metal lath over burlap. A Fairbanks-Morse pump had a capacity of 4000 gallons per minute. Power was furnished by a Fairbanks-Morse 85-horsepower Diesel engine. A Fairbanks-Morse 1500-watt generator supplied the lights. Nine men were employed on two shifts.

Tehama Dredging Company. T. A. Dailey, Tom R. Howard, Ben R. Howard, and W. R. Dailey, co-partners, operated a dragline dredge on the west side of the Sacramento River in secs. 35 and 36, T. 29 N., R. 3 W. on land leased from Joseph F. Nunes, in 1939. Equipment included a Northwest Dragline shovel, 35-foot boom, ¾-yard bucket, powered by a 6-cylinder Wisconsin motor. The washing plant was mounted on a 24- by 20-foot wooden hull and included a 4- by 19-foot trommel with 10 feet of ⅜-inch holes. The stacker belt was 24 inches wide and 30 feet long. There were five 2- by 6-foot sluices on each

DRAGLINE DREDGE OF MIDLAND COMPANY

Reprinted from California Journal of Mines and Geology for April 1938, page 119

side using expanded metal over gunny sacking. The tail sluices were 2 feet wide and were fitted with Hungarian riffles. Power was furnished by an Allis-Chalmers U-40 engine using stovetop fuel. Water was supplied by a 6-inch Deming centrifugal pump.

Commercial sand and gravel plant operators in the vicinity of Red Bluff have not found that the gold content of the material they handled was enough to pay for trying to recover it.

Magnesite

S. D. Furber of Corning and seven associates have located *El Soledad, Big Slide,* and *Big Springs* group of claims, containing 480 acres in sec. 22, T. 25 N., R. 7 W., for magnesite, but little development work has been done on them to date.

Manganese

The manganese deposits so far discovered in Tehama County occur in seams and lenses in the Franciscan cherts and metamorphic rocks that strike northwest along the eastern slope of the Coast Ranges. The deposits discovered to date have been small, low grade, and high in silica, so there has been little development and no production reported. The following deposits are noted:

Name	Remarks	Sec.	Township	Range	References
Cavaleri	Probably abandoned	14	24 N.	7 W.	R.XV, 262; B. 126, p. 193.
Elva	Probably abandoned	30	23 N.	7 W.	R.XXIV, p. 214; R. XV, p. 262; B. 76, p. 87; B. 126, p. 193.
Lockwood	Section owned by Paul and Florence Jeffers	9	23 N.	7 W.	B. 76, p. 88; B. 126, p. 193.
Logan	Probably abandoned	17	23 N.	7 W.	B. 126, p. 193.
Manganese King	Probably abandoned	NE 8	27 N.	9 W.	B. 126, p. 193.
Manganese Peak	Probably abandoned	20	23 N.	7 W.	R. XV, p. 262; B. 76, p. 88; B. 126, p. 193.
Tehama	Probably abandoned	1, 2, 11, 12	26 N.	10 W.	B. 126, p. 193.

Mineral Springs

There are several well-known mineral springs in Tehama County that formerly had accommodations for paying guests; but because of destructive fires or change of ownership they are no longer commercialized. The following descriptions of springs are taken from U. S. Geological Survey Water-Supply Paper 338, *Springs of California,* by G. A. Waring, pp. 266-267, and from earlier Reports of the State Mineralogist as cited.

Battle Creek Meadows (White Sulphur Springs). These springs are located in sec. 20, T. 29 N., R. 4 E.

"There is a small cool sulphur spring about 1½ miles northeast of Mineral post office, which is near the southern base of Lassen Peak. It issues in a ravine 15 yards from the eastern bank of Summit Creek, and about 150 yards east of the stage road. The spring issues from basaltic lava, at the rate of 8 gallons per minute, of cold, noticeably sulphureted water, which deposits small amounts of sulphur. It is the only cold spring seen in the Lassen Peak region, the other sulphur springs being of a notably thermal character."

Irma Gerber Starkweather, owner.

Bibl: State Mineralogist's Report XV, p. 266.

Colyear Springs. Colyear Springs are in sec. 30, T. 26 N., R. 7 W.

"These springs are situated high on the mountain-side north of the North Fork of Elder Creek, 35 miles west of Red Bluff. Six springs here rise in a cemented place 5 yards in diameter, among the pine trees, on a moderate slope. One of the largest yields cold sulphur water, while the others are only slightly sulphureted. On the slope about 8 yards above these springs, there is a clear water spring that yields 4 to 5 gallons a minute."

R. L. Owens of Red Bluff is now the owner.

Bibl: State Mineralogist's Report XV, p. 262.

Hensley Spring. Hensley spring is owned by Mary F. Braynard.

"Sec. 14, T. 26 N., R. 8 W. is about 4 miles by trail west of north from Colyear Springs and about 450 feet lower down the mountainside. It rises at the edge of a clump of black oaks, on a low ridge between two ravines in an area that is covered with dense brush. It furnishes sufficient water for plant growth, forming a small green patch within which there are a few willow trees. The spring rises partly as seepage and partly from a shallow basin in the soil. Its water is noticeably sulphureted and deposits a small amount of iron. The spring has long been known, but the place has been abandoned since the early nineties, and a cabin that stood near the spring was destroyed by a brush fire several years ago. A much smaller spring, similar in character to Hensley Spring issues in the bed of a ravine a mile southward. These springs are undeveloped."

Bibl: U.S.G.S. W.-S. P. 338, p. 266.

Hickman Mineral Salt Spring (Tehama Mineral Spring). Hickman spring is located in sec. 16, T. 25 N., R. 7 W., and is undeveloped. The land is owned by the State of California.

Morgan Hot Springs. These springs are located in sec. 14, T. 29 N., R. 4 E.

"They are situated on the Morgan Ranch, about 50 miles northeast of Red Bluff. There are a group of 25 springs and pools scattered for a distance of ¼ mile in a meadow along Mill Creek; this meadow is termed Big Hot Spring Valley. Most of them are quiet pools of small flow, as a rule less than 5 feet in diameter and relatively shallow. A number of them contain thick algous growths, and several deposit native sulphur. A number of springs steam and sputter from vents in a hard conglomerate along the banks of the creek. One of the northernmost of these springs seems to have a true geyser action, for it issues from a shallow basin 3 feet in diameter, in which the water comes to a state of vigorous ebullition and then subsides."

The place was once used as a summer resort but it is now owned by R. W. Hanna of San Francisco, and no commercial use is made of the springs.

Bibl: State Mineralogist's Report XV, p. 263; R. XXIV, p. 215.

Tuscan Springs. This place is now owned by George W. Kramer and associates and no commercial use is being made of it.

"NE. ¼ Sec. 32, T. 28 N., R. 2 W., these springs are situated 10 miles northeast of Red Bluff, near the head of the canon of Salt Creek. Tuscan Springs were dis-

NORTHERN OIL AND GAS COMPANY DERRICK, NEAR PASKENTA

DRAPER AND ADAMS
Commercial sand and gravel plant, Red Bluff

covered in 1856 by Dr. John A. Veatch, who in a chemical examination of the waters, discovered crystals of borax, said to be the first borax found in the State. The springs are situated at an elevation of 1000 feet above sea level. The canon of Salt Creek widens at its head to a small valley surrounded by rugged cliffs, and the springs issue along the main creek and its branches in this open area."

"The springs rise in a dark shale and sandstone, the latter material being veined in places by calcite. The structure shows that the beds have been folded into a small arch or anticline. Dips of 50° on the western side of the fold are observed."

"The occurrence of usable quantities of illuminating gas is worthy of mention in connection with this anticlinal structure. The sediments are overlain by volcanic tuff, which forms the cliffs of the canon walls. As many as 50 springs are claimed for the locality. Spring houses protect some of those that are most used for drinking purposes. Water from another spring supplies evaporating trays, in which occasional amounts of medicinal salts are prepared for sale. Two other springs rise in cemented reservoirs about 15 to 20 feet in diameter. Gas from one of these, which is called the Natural Gas Spring, is piped to a tank higher on the hillside for use in hotel and cottages; and water from the other spring, which is called the Fountain Spring, supplies the baths and swimming pool. Most of the springs rise in brick and cemented basins. All springs are within 250 yards southeast of the hotel, which is on higher ground overlooking them. Most of the springs have a small flow, but all are strongly mineralized. Some are strongly sulphureted as well as saline. Analyses indicate that they are primary saline waters, remarkably uniform in composition for springs of such high mineral content, the chief difference being in the high sulphate content of Spring No. 1. There is a remarkably high potassium content in all but the Natural Gas Spring."

Bibl: State Mineralogist's Report XV, p. 263; R. XXIV, p. 215.

Natural Gas

The occurrence of usable amounts of natural gas in several wells in the vicinity of Flournoy, sec. 21, T. 24 N., R. 5 W., and at Tuscan Springs, in sec. 32, T. 28 N., R. 2 W., have encouraged oil companies to drill wells in search of commercial amounts of oil and gas in Tehama County.

Superior Oil Company made a gas discovery at its well "Saldubehere" No. 1, sec. 12, T. 24 N., R. 3 W., in 1944. As reported in the "Summary of Operations, California Oil Fields," vol. 30-no. 2, page 61:

"This is the most northerly occurrence of commercial gas yet discovered in the Sacramento Valley. The well was drilled to a depth of 9225 feet, which was still not in basement rocks. Casing was cemented and a series of tests made of some Cretaceous sands from 4662 to 4050 feet, but only salt water was recovered."

"The well was finally completed on October 21, 1944, from a gas zone, 1070 to 1504 feet, in Tehama formation. A series of short tests were made, resulting in a maximum daily rate of flow of 17,676 Mcf., with tubing and casing pressures of 380 and 485 pounds respectively. Shut in pressure was 660 pounds."

In January 1946 the well was still shut in, and no commercial sale of gas has been made to date.

Richfield Oil Corporation drilled two wells a few miles to the north in sec. 26, T. 25 N., R. 3 W., to depths of 4100 and 4320 feet, and abandoned them in 1944.

Northern Oil and Gas Company, Room 401, Phelan Building, San Francisco, started drilling about 2 miles west of Paskenta in November 1945 on the Tait Ranch in sec. 1, T. 23 N., R. 7 W. Drilling was suspended in December at a depth of 1901 feet because of unusually heavy rains. The company was expected to resume drilling again in the spring of 1946.

Shallow wells from which gas flows have been reported were drilled in:

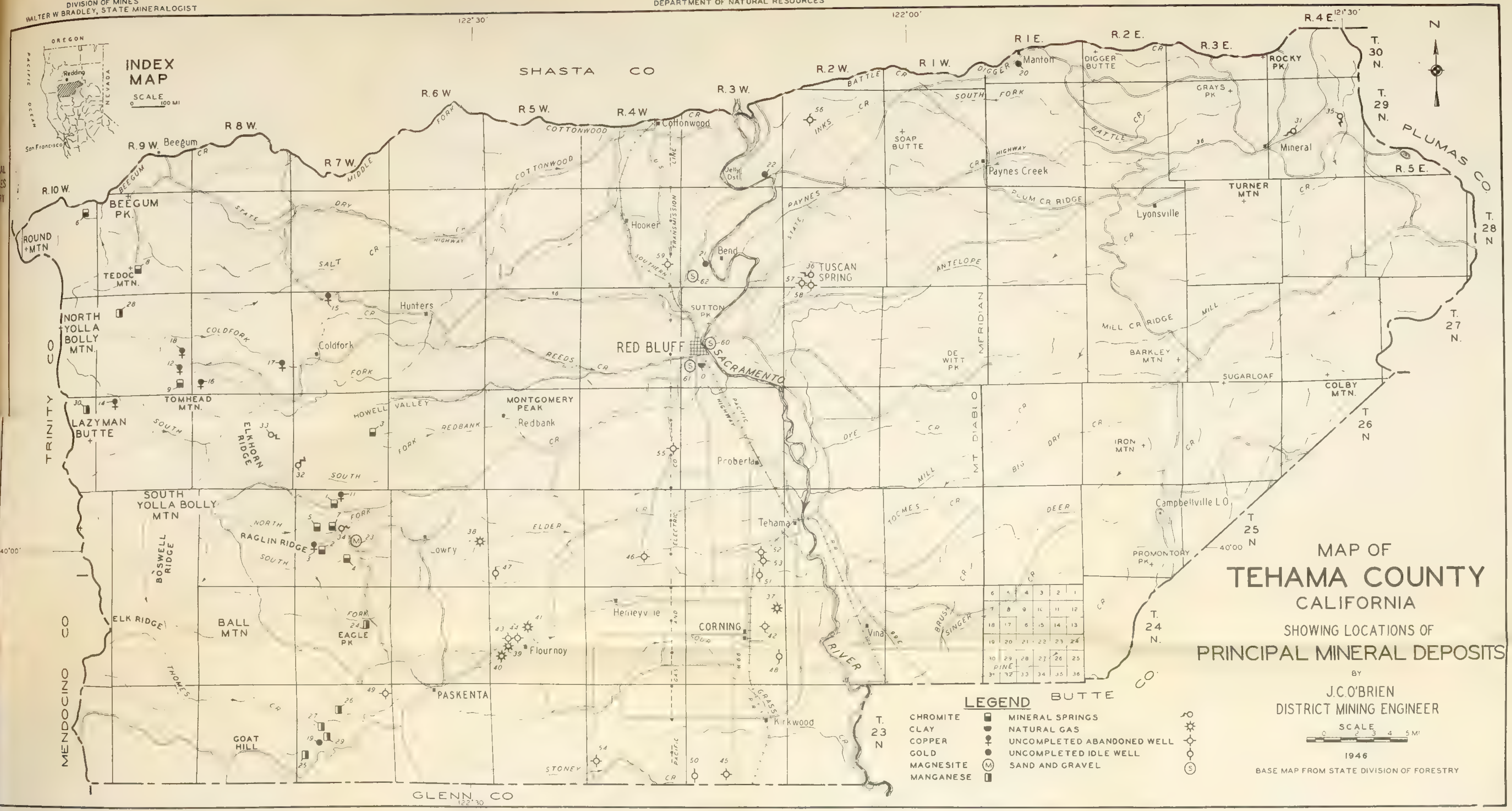
Data on wells drilled in Tehama County as reported in 35th Report, pages 221-253; Bulletin 118, page 662; and Summary of Operations, California Oil Fields

T.	R.	Sec.	B. & M.	Name of company and well	Year abandoned or last active	Depth in feet	Geology at bottom
29 N.	2 W.	8	M.D.	Texas Co. "Jelly Bend" 18-8	1944	7134	Granite (?)
28 N.	7 W.	12	M.D.	Burgess, Irvin S. Well #1	(?)	(?)	(?)
28 N.	4 W.	25	M.D.	Tuscan Oil Co. Well No. 1	1922	1845	
28 N.	2 W.	32	M.D.	Texas Co. "Walbridge" 1	1942	1068	
28 N.	2 W.	32	M.D.	Texas Co. "Walbridge" 1A	1943	3045	High water Pressure (?)
26 N.	4 W.	24	M.D.	Tehama Co. Oil Co. & Hooker Dome Oil Co., Well No. 1	1924	575	
25 N.	5 W.	31	M.D.	Marker Drilling Co. Well No. 1	1936	4425	Cretaceous
25 N.	4 W.	27	M.D.	Los Chicos Oil Co. Well No. "Scharr" 1	1936	2650	
25 N.	3 W.	35	M.D.	Richfield Land Co. Well No. 10	Pre 1937	524	
25 N.	3 W.	26	M.D.	Richfield Oil Corp. "Gallatin" 1	1944	4320	
25 N.	3 W.	26	M.D.	Richfield Oil Corp. "Gallatin" 1A	1944	4100	
24 N.	5 W.	20	M.D.	Crockett Drilling Syn., Inc. (Burgess & Goodale) Well No. 1	1931	1885	Cretaceous
24 N.	5 W.	20	M.D.	Crockett Drilling Syn., Inc. Well No. 3	1936	2101	Cretaceous
24 N.	3 W.	14	M.D.	Apex Drilling Co. Well No. "Flood" 1	1940	200+	
24 N.	3 W.	12	M.D.	Superior Oil Co., "Saldubehere" 1	1944	9225	Gas Zone 1070-1504 ft.
24 N.	3 W.	25	M.D.	Northern Counties Pet. Co. Well No. "Ewers-Mooney" 1	1936	8253	Cretaceous
23 N.	4 W.	30	M.D.	Stella, E. F. Trustee, Well No. "Johnston" 2	1939	3326	Cretaceous (?)
23 N.	3 W.	33	M.D.	General Petroleum Corp. "Dolan" 1	1944	3589	
23 N.	3 W.	31	M.D.	Orland Oil Syn. Ltd. Well No. "Johnston" 1	1934	3780	Cretaceous (?)
23 N.	1 W.	11	M.D.	Pacific Western Oil Corp. and George F. Getty Inc. Independent Exploration Co. "Cana" 1	1943	6939	Cretaceous (?)

DIVISION OF MINES
WALTER W. BRADLEY, STATE MINERALOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

PLATE 28



ACCOMPANYING STATE MINERALOGIST'S REPORT XLII, JULY 1946

LIST OF PRINCIPAL MINERAL DEPOSITS TEHAMA COUNTY, CALIFORNIA

Map No.

CHROMITE

1 Basler Mining & Development Co., secs. 4, 8, T. 25 N., R. 7 W.
2 Big Bear chrome mine, NE ¼ sec. 20, T. 25 N., R. 7 W.
3 Hensley & Hazelwood, secs. 13, 14, T. 26 N., R. 7 W.
4 Kleinsorge, sec. 27, T. 25 N., R. 7 W.
5 McLaughlin & Applegarth (Grau mine), sec. 17, T. 25 N., R. 7 W.
6. Moore & Robinson (Beegum mine), secs. 11, 12, T. 28 N., R. 10 W.
7 Noble Electric, sec. 16, T. 25 N., R. 7 W.
8 Tedoc chrome mine, sec. 28, T. 28 N., R. 9 W.
9 Toms Head mine, sec. 36, T. 27 N., R. 9 W.

CLAY

10 O'Connor Bros., sec. 29, T. 27 N., R. 3 W.

COPPER

11 Basler (White Bluff group), sec. 4, T. 25 N., R. 7 W.
12 California & Massachusetts, sec. 25, T. 27 N., R. 9 W.
13 Elder Creek group, sec. 20, T. 25 N., R. 7 W.
14 Halley, sec. 5, T. 26 N., R. 9 W.
15 Kestner & Thompson, sec. 4, T. 27 N., R. 7 W.
16 Tom Head, sec. 31, T. 27 N., R. 8 W.
17 Uncle Sam, sec. 25, T. 27 N., R. 8 W.
18 Verde, sec. 24, T. 27 N., R. 9 W.

GOLD

19 Bowers Creek mine, sec. 20, T. 23 N., R. 7 W.
20 Joe Arnol prospect, sec. 28, T. 30 N., R. 1 E.
21 Midland Dredging Co., sec. 29, T. 28 N., R. 3 W.
22 Tehama Dredging Co., secs. 35, 36, T. 29 N., R. 3 W.

MAGNESITE

23 El Soledad, Big Slide, and Big Springs group, sec. 22, T. 25 N., R. 7 W.

MANGANESE

24 Cavaleri, sec. 14, T. 24 N., R. 7 W.
25 Elva, sec. 30, T. 23 N., R. 7 W.
26 Lockwood, sec. 9, T. 23 N., R. 7 W.
27 Logan, sec. 17, T. 23 N., R. 7 W.
28 Manganese King, sec. 8, T. 27 N., R. 9 W.
29 Manganese Peak, sec. 20, T. 23 N., R. 7 W.
30 Tehama, secs. 1, 2, 11, 12, T. 26 N., R. 10 W.

MINERAL SPRINGS

31 Battle Creek Meadows, White Sulphur Springs, sec. 20, T. 29 N., R. 4 E.
32 Colyear Springs, sec. 33, T. 26 N., R. 7 W.
33 Hensley Springs, sec. 14, T. 26 N., R. 8 W.
34 Hickman Mineral Salt Springs, Tehama Mineral Spring, sec. 16, T. 25 N., R. 7 W.
35 Morgan Hot Spring, sec. 14, T. 29 N., R. 4 E.
36 Tuscan Springs, NE ¼ sec. 32, T. 28 N., R. 2 W.

NATURAL GAS

37 Superior Oil Co. "Saldubehere" 1, sec. 12, T. 24 N., R. 3 W.

Shallow wells reported producing useable amounts of gas

38 Sec. 24, T. 25 N., R. 6 W.
39 Sec. 20, T. 24 N., R. 5 W.
40 Sec. 30, T. 24 N., R. 5 W.
41 Sec. 16, T. 24 N., R. 5 W.

Other Wells

42 Apex Drilling Co., well no. "Flood" 1, sec. 14, T. 24 N., R. 3 W.
43 Crockett Drilling Syn., Inc. (Burgess & Goodale) well no. 1, sec. 20, T. 24 N., R. 5 W.
44 Crockett Drilling Syn., Inc. well no. 3, sec. 20, T. 24 N., R. 5 W.
45 General Petroleum Corp. "Dohn" no. 1, sec. 33, T. 23 N., R. 3 W.
46 Los Chicos Oil Co. well no. "Scharr" 1, sec. 27, T. 25 N., R. 4 W.
47 Marker Drilling Co. well no. 1, sec. 31, T. 25 N., R. 5 W.
48 Northern Counties Pet. Co. well no. "Ewers-Mooney" 1, sec. 25, T. 24 N., R. 3 W.
49 Northern Oil & Gas Co., sec. 1, T. 23 N., R. 7 W.
50 Orland Oil Syn. Ltd. well no. "Johnston" 1, sec. 31, T. 23 N., R. 3 W.
51 Richfield Land Co., well no. 10, sec. 35, T. 25 N., R. 3 W.
52 Richfield Oil Corp. "Gallatin" 1, sec. 26, T. 25 N., R. 3 W.
53 Richfield Oil Corp. "Gallatin" 1A, sec. 26, T. 25 N., R. 3 W.
54 Stead, E. E., Trustee, well no. "Johnston" 2, sec. 30, T. 23 N., R. 4 W.
55 Tehama Co. Oil Co. & Hooker Dome Oil Co., well no. 1, sec. 24, T. 26 N., R. 4 W.
56 Texas Co. "Lily Bend" 18-8, sec. 8, T. 29 N., R. 2 W.
57 Texas Co. "Walbridge" 1, sec. 32, T. 28 N., R. 2 W.
58 Texas Co. "Walbridge" 1A, sec. 32, T. 28 N., R. 2 W.
59 Tuscan Oil Co. well no. 1, sec. 25, T. 28 N., R. 4 W.

SAND AND GRAVEL

60 Draper & Adams, sec. 20, T. 27 N., R. 3 W.
61 Frederickson & Westbrook, sec. 30, T. 27 N., R. 3 W.
62 A. S. Jones and R. P. King, sec. 31, T. 28 N., R. 3 W.

Township	*Range*	*Section*	*B. & M.*
25 N	6 W	24	M.D.
24 N	5 W	20	M.D.
24 N	5 W	30	M.D.
24 N	5 W	16	M.D.

Platinum

Platinum has been recovered by panning the material taken from crevices in the slate bedrock of Beegum Creek along the northwest boundary of Tehama County. Values were confined to a short distance along the channel where the grade was steep enough to clear the bed of sand. The slate formation, which crosses the creek bed at almost a right angle, dips flatly east in the direction of flow and forms a natural riffle. Mr. C. A. Logan made a study of this district in 1918 and his observations are recorded in Division of Mines Bulletin 85, *Platinum and Allied Metals in California,* pages 48-50. An analysis of the platinum recovered from Beegum Creek reported by Shapleigh in U. S. Geological Survey Bulletin 193 states that the metal assayed 13.5-20 percent platinum and from 79.0-84 percent osmiridium.

Sand and Gravel

Draper and Adams, 315 Walnut Street, Red Bluff, are operating a commercial sand and gravel plant on the Sacramento River bank in sec. 20, T. 27 N., R. 3 W., on land owned by the Howell estate. The material is screened into four sizes, minus $1\frac{1}{2}$-inch plus $\frac{3}{4}$-inch; minus $\frac{3}{4}$-inch plus $\frac{3}{8}$-inch; minus $\frac{3}{8}$-inch plus $\frac{1}{4}$-inch; and sand, minus $\frac{1}{4}$-inch; and is stored in six 50-ton capacity bunkers. The maximum size of material in this pit is about 12 inches. Everything that passes through the $\frac{1}{4}$-inch screen is classed as sand, and the material handled averages about 35 percent sand and 65 percent gravel. The plant is designed to handle 100 tons per hour. All equipment is powered by electric motors and all motors except for the sand rolls can be controlled at the power switchboard. Material is sold for concrete aggregate. Two men are employed at the plant. Harold Eggleston is manager.

Jack Hein operated a sand and gravel plant just south of this property in 1940.

Frederickson and Westbrook, Box 369, Red Bluff, operated a sand and gravel plant on the Hulseman Ranch at Reeds Creek, sec. 30, T. 27 N., R. 3 W. in 1941. They produced sand and gravel and mixed oiled road material which was used in building the Red Bluff airport. The plant had a capacity of 125 tons per hour and seven men were employed.

A. S. Jones and *R. P. King* of Haywood operated a sand and gravel plant in the creek bed east of the highway about 3 miles north of Red Bluff, sec. 31, T. 28 N., R. 3 W., in 1941. The material was used in paving 6 miles of highway. The plant was dismantled when the road was completed.

GEOLOGIC BRANCH

CURRENT NOTES

By Olaf P. Jenkins*

In this issue

The geology of the large and important Mayacmas quicksilver district of northern California is featured in this issue of the *California Journal of Mines and Geology.* Edgar H. Bailey describes the western part, lying in Sonoma County; Robert G. Yates and Lowell S. Hilpert cover the eastern area in Lake and Napa Counties. This work has been contributed by the United States Geological Survey, and represents a part of the cooperative program between the State and Federal departments.

Mr. M. Vonsen contributes to this issue a report on the mineralogy of the region about ''The Geysers,'' Sonoma County. This is especially significant in respect to the quicksilver mineralization of the district.

In press

The following geological reports (cooperative work between the State Division of Mines and Federal Survey) are now in press: (1) Bulletin 129, *Iron Resources of California;* Parts A-J have already been released in preprint form; (2) *Chromite Deposits of Del Norte County, California,* by Francis G. Wells, Fred W. Cater, Jr., and Garn A. Rynearson, which is the first chapter of Part I of Bulletin 134, *Chromite Deposits of California;* (3) *Chromite Deposits of the Northern Coast Ranges in California,* by D. H. Dow and T. P. Thayer, which is chapter 1 of Part II of the same bulletin.

Also in press, and due to be released shortly, is Bulletin 133, *Geology of the San Juan Bautista Quadrangle,* by John Eliot Allen. This report is accompanied by a colored lithographed map of the quadrangle, scale 1:62500.

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* Chief Geologist, California State Division of Mines.

PROGRESS ON REVISION OF BULLETIN 113, "MINERALS OF CALIFORNIA," WITH NOTES ON SOME NEW OCCURRENCES

By Joseph Murdoch*

A very comprehensive search of the literature for references to occurrences of minerals in California has been completed, and the work of sorting and selecting these has been commenced. It has not been possible to find written authority for all occurrences listed in the earlier editions of *Minerals of California,* but all later entries have reliable confirmation. It is planned to indicate for each entry the degree of validity involved. Thus, an occurrence clearly recorded in a scientific publication, or one which is confirmed by unpublished information from a reputable source, would be considered as first class. Occurrences mentioned in the reports of correspondents from mining districts, and those to which other written reference was not so clear, would be called fair, while occurrences concerning which a flat, unsupported statement is made, or which are confirmed only by hearsay, would in large measure be eliminated. Many of the undocumented references carried in the earlier editions of the Bulletin, some of them inherited from successively earlier statements, were probably from Eakle's personal experience, and would be included in the forthcoming edition. This would be particularly the case for references which are elaborated by confirmatory detail as to the character of the mineral, or association and occurrence. Others, simple bald and otherwise unsupported statements, would probably be thrown out.

In addition, it is planned to use somewhat greater selectivity, particularly in the case of very common minerals, such as galena, and offer more generalized statements concerning occurrence, accompanied by specific references only in the case of those localities offering some points of special interest, such as well developed crystals, notable commercial interest, etc. The less common minerals would have more inclusive coverage, and the occurrence of the rarer ones would of course be completely recorded. In the mineral descriptions, the crystallography will be simplified, and lists of crystal forms ordinarily omitted.

It is planned to include a brief section on the history of the mineralogical (and geological) work in the State, largely abstracted from F. M. Anderson's *Pioneers in the Geology of California,* in Shedd's Bibliography, Division of Mines Bulletin 104. A very brief mention may be made of the use of minerals by the native Indians and aborigines. Several of the more famous mineral localities of the State will be described briefly, with the idea of assembling in one place a comprehensive list of the minerals found at each.

In the arrangement of minerals in the Bulletin, some consideration has been given to an alphabetical form, rather than the new Dana classification. There seem to be some advantages, and some drawbacks, to this "dictionary" arrangement, and the writer would appreciate any expressions of opinion, pro or con. In any case, there will be a table of the minerals by elements, and in the case of the alphabetical arrangement, or perhaps in any event, an outline list of California minerals according to the Dana classification.

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* Department of Geology, University of California, Los Angeles. Manuscript submitted for publication April 30, 1946.

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The new occurrences of minerals which I wish to record are all from pegmatites. At Rincon, in San Diego County, a small pegmatite carries, at one section of its outcrop, an abundance of rather rough crystals of *spodumene,* tabular in form, and ranging up to 6 inches in length by 3 or more in width. These occur in quartz, possibly as a replacement. Associated with the spodumene, and in part replacing it, are *petalite* (the rare sub-silicate of lithium and aluminum) in divergent groups of slender prisms, and *heulandite,* which is usually massive, but occasionally shows typical tabular crystals. These two minerals are as a rule very intimately intergrown, and the petalite can be purified only by dissolving out the heulandite. In addition, in this spodumene-heulandite-petalite aggregate, are scattered bright yellow grains of *helvite,* showing an occasional crystal face, but not enough to enable the form to be recognized. Differentiation from garnet was accomplished by the recently developed arsenic sulphide test, which is easy to make, and very definite.

Another occurrence is in the pegmatite of the Southern Pacific silica quarry at Nuevo, in Riverside County. Here nests of radiating square prismatic greenish to brownish crystals of *cyrtolite* are associated with *xenotime* and *monazite.* In some cases the cyrtolite is intergrown in parallel position with xenotime, exactly as shown in the textbook illustrations. One loose specimen was collected which was made up of an aggregate of crude black crystals in a quartz matrix. These crystals are orthorhombic in their symmetry, prismatic or thick tabular in habit, and range in size up to an inch in length. The fresh surface shows a brilliantly pitchy luster, with flat conchoidal fracture. The color is black, but in very thin flakes the mineral is yellowish brown by transmitted light. In spite of the orthorhombic form, these flakes appear to be isotropic. The index of refraction is 2.23±. The specific gravity is 6.4, determined on pure fragments. The hardness is about 6.5. Spectroscopic analysis shows it to be a titanoniobate of yttrium and iron, and tests show it to carry a small amount of water. A chemical analysis is being made, but is not yet at hand. Its description does not seem to agree with any known mineral, and it may be a new species.

QUICKSILVER DEPOSITS OF THE WESTERN MAYACMAS DISTRICT, SONOMA COUNTY, CALIFORNIA *

By Edgar H. Bailey **
U. S. Department of the Interior, Geological Survey

OUTLINE OF REPORT

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior. Manuscript submitted for publication December 1945.
** Geologist, U. S. Geological Survey.

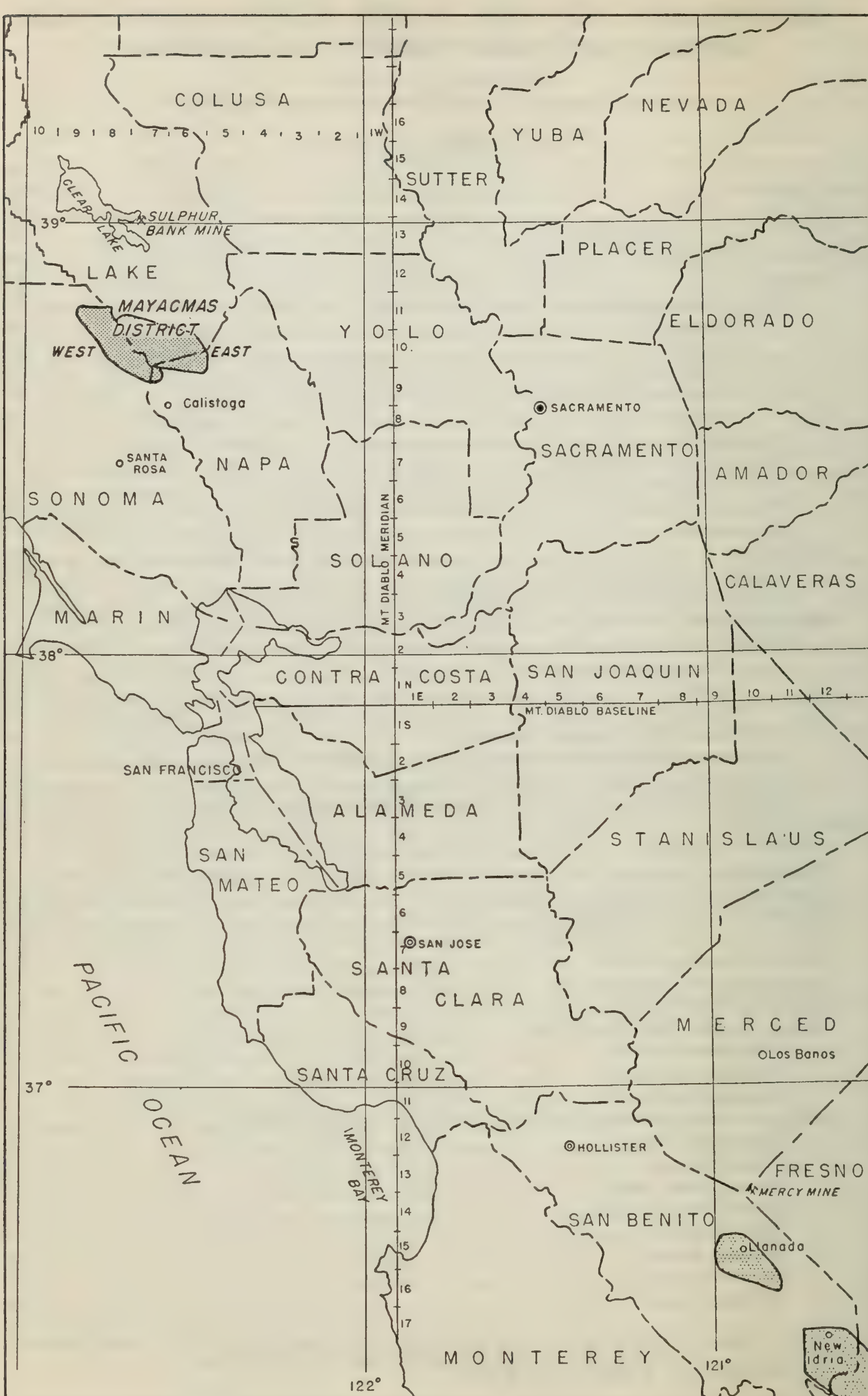

FIG. 1. Index map of a part of California, showing the location of the Western Mayacmas quicksilver district.

ABSTRACT

The Mayacmas district, which is 50 miles north of San Francisco Bay, ranks as the second most productive quicksilver district in California. Only the western part of the district, lying in Sonoma County, is dealt with in this report. Quicksilver was first mined in this part of the district in 1861, and by the end of 1944 about 36,000 flasks had been recovered.

A thick sequence of sedimentary and volcanic rocks belonging to the Jurassic(?) Franciscan group occupies most of the mapped area. The strata strike northwesterly and dip steeply to the northeast. They are cut by sinuous, nearly vertical bodies of serpentine intruded along northwesterly trending shear zones. In places these intrusions have been hydrothermally altered to silica-carbonate rock, which contains many of the ore bodies. Slightly tilted andesitic flows and tuffs, tentatively correlated with the Pliocene Sonoma volcanics, cap the highest parts of the main Mayacmas Range. A long belt containing steam vents and hot springs, including The Geysers, extends nearly parallel to the strike of the strata of the Franciscan group and the serpentine intrusions, but the present hydrothermal activity differs from that which gave rise to the quicksilver ore bodies.

Ore bodies occur where cinnabar or native mercury, or both, were deposited from hydrothermal solutions rising through major shear zones. As most of these zones are filled with serpentine, most of the mines lie along the borders of serpentine masses in lenses of silica-carbonate rock; however, the most productive mine—the Cloverdale mine—lies in chert along a fault zone that contains no serpentine. The ore minerals generally were deposited in small openings, so that the ore bodies may be referred to as stockworks, irregular veins, or pipes. These ore bodies were localized beneath inclined faults by small structural features such as splits in the faults, the flat parts of faults, or bends of the faults toward their footwalls forming inclined inverted troughs.

Reserves in known ore bodies are very small, and before the district can again yield 1,000 flasks of quicksilver a year, as it sometimes has in the past, extensive exploration will be necessary.

INTRODUCTION

The Mayacmas district, which ranks as the second most productive quicksilver district in California, is a northwesterly trending belt about 25 miles long, with its center 50 miles north of San Francisco Bay (see fig. 1). The belt includes the line separating Lake and Sonoma Counties and extends southeastward into Napa County. This report deals only with the part of the district that lies in Sonoma County; the geology of the eastern part of the belt is treated in a separate report.[1] The entire district yielded 425,000 flasks of quicksilver between 1860 and 1944, but of this total only about 36,000 flasks have come from the western part.

The Western Mayacmas district extends from the foothills bordering the Russian River-Maacamas Creek valley to the divide of the Mayacmas Range. In the eastern part of the area, near Calistoga, the slopes rise abruptly from the valley to Mount St. Helena, which has

[1] Yates, Robert G., and Hilpert, Lowell S., Quicksilver deposits of the Eastern Mayacmas district, Lake and Napa Counties, California: California Jour. Mines and Geology, vol. 42, pp. 231-286, 1946.

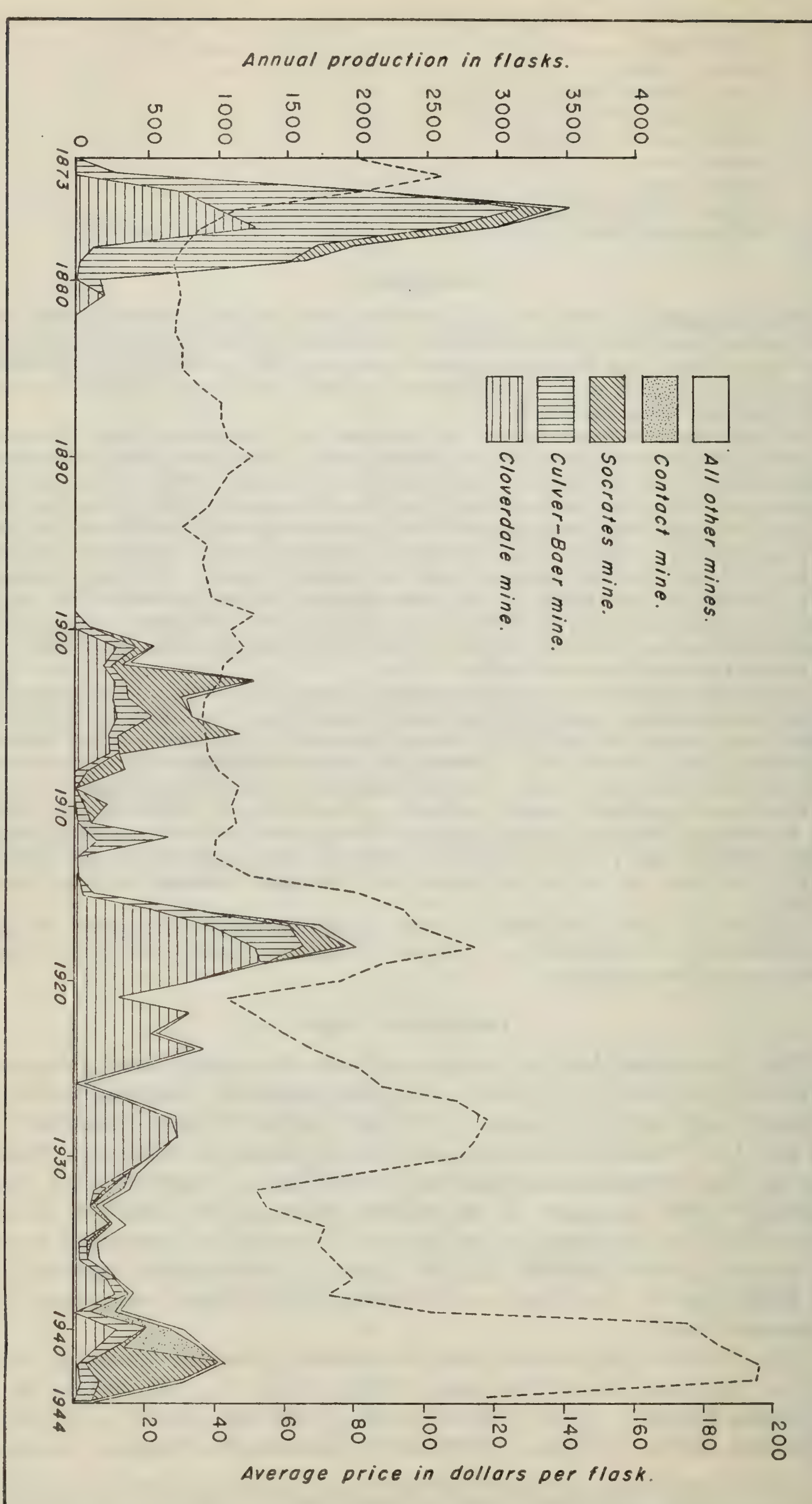

Fig. 2. Graph showing the annual production of quicksilver in the Western Mayacmas district, California, and the average annual price per flask.

an altitude of 4262 feet and is one of the highest points on the divide. In the western part several longitudinal valleys, of which the best developed is Sulphur Creek Canyon, cut the range into northwesterly trending ridges (see pl. 29). In the northwestern corner of the area, well within the range, the bottom of the valley of Sulphur Creek is only 900 feet above sea level. The topography is moderately rugged, but most of the area is covered by at least a thin mantle of soil, and extensive rock outcrops are not common. The vegetation ranges from conifers in the higher and damper parts to dense brush and, on the lower slopes, open grassland. Most of the area is readily accessible by roads extending from points along the Russian River-Maacamas Creek valley to scattered upland ranches.

Little geologic work had been done in the region before 1941. Forstner[2] made a reconnaissance map prior to 1903, and a small part of the area was described by C. P. Ross[3] in 1938. The Geysers, and other hydrothermal areas in the same belt, have been the object of intensive study by Allen and Day.[4]

The field work that forms the basis for this report was done in the fall of 1941 and in the fall and winter of 1942-43. Most of the areal geology was plotted on aerial photographs and later fitted to enlargements of parts of the Kelseyville, Lower Lake, Healdsburg, and Calistoga quadrangles. The northeastern end of the area, between the Black Bear and the Cloverdale mines, was mapped directly on a topographic base.

The writer was capably assisted in the field by Fred B. Roberts in 1941, and by James B. Cathcart, Philip F. Fix, David A. Phoenix, and C. Melvin Swinney in 1942-43; it is a pleasure for him to acknowledge his indebtedness to them. All the mine owners and operators in the district were most cordial and helpful, giving freely of their time and knowledge. The writer wishes also to express his appreciation to E. B. Eckel, Howel Williams, A. C. Waters, and F. C. Calkins of the Geological Survey for advice during the field work and in the preparation of this report.

HISTORY AND PRODUCTION

The total recorded production of the district since the beginning of quicksilver mining in 1861 to the end of 1944 is 36,000 flasks. The annual production since 1872 for each of the four largest mines, and for all the other mines together, is shown in figure 2. As the production has nearly all come from four mines, and as one of these operated on large bodies of low-grade ore while the other relied on smaller but richer pockets, the production of the district mirrors with remarkable fidelity the interplay between fluctuating quicksilver prices and increasing mining costs and decreasing reserves.

The occurrence of quicksilver minerals in the vicinity of The Geysers was noted in the early 1850's,[5] but active mining did not begin until 1861,[6] when the Pioneer mine, now known as the Socrates, and possibly

[2] Forstner, Wm., The quicksilver resources of California: California Min. Bur. Bull. 27, map, p. 35, 1907.
[3] Ross, C. P., Quicksilver deposits of the Mayacmas and Sulphur Bank districts, California: U. S. Geol. Survey, Bull. 922-L, pl. 49, p. 330, 1940.
[4] Allen, E. T., and Day, A. L., Steam well and other thermal activity at "The Geysers," California: Carnegie Inst. Washington, Pub. 378, 1927.
[5] Mining and Scientific Press, vol. 30, p. 66, Jan. 30, 1875.
[6] Ransome, A. L., and Kellogg, J. L., Quicksilver resources of California: California Jour. Mines and Geology, vol. 35, p. 470, October 1939.

other mines in the Pine Flat area were first worked. Production in the late sixties and early seventies is unrecorded and doubtless was small, but in the late seventies, in response to a rise in the price of quicksilver to more than $100 a flask, the entire district experienced a boom. During this period the Cloverdale mine was developed to produce over 1000 flasks a year, and the Missouri, Geyser, and Lost Ledge (Oakland) mines, later combined as the Culver-Baer mine, attained a production of about 2000 flasks a year. Other mines, such as the Sonoma, Rattlesnake, Flagstaff or Eureka, and Kentuck (now the Black Bear), were developed and probably had a small though unrecorded production. From 1882 to 1899 the price of quicksilver fluctuated between $30 and $50 a flask, and, as a result, all the mines were virtually idle. Between 1900 and 1913 the Cloverdale and Socrates mines, and to a lesser extent the Culver-Baer mine, were again operated, but production dropped to almost nothing in 1913 and 1914. During World War I, in response to a rise in price to over $120 a flask, the same mines again became active, but the smaller ones, though reopened and developed, failed to yield any appreciable quantity of metal. Since that time, production at the Cloverdale mine has steadily declined, and the Culver-Baer and Socrates mines were nearly idle until stimulated by the sharp rise in prices beginning in 1939. Between 1939 and 1943, partly owing to the development of safe methods of working ore containing native mercury, the Contact and Socrates mines had a substantial production. After the fall of the price of quicksilver to about $100 early in 1944, only small-scale operations were maintained at a few of the mines.

GENERAL GEOLOGY

Most of the area shown in the geologic map (pl. 29) is occupied by a thick sequence of sedimentary and volcanic rocks belonging to the Jurassic (?) Franciscan group. These rocks have a prevalent northwesterly strike, and in most places they dip steeply to the northeast. They are cut by sinuous, nearly vertical masses of serpentine, intruded along northwest trending fault zones. The outcrops of the serpentine form a pattern somewhat like that of braided stream channels. In places the serpentine has been hydrothermally altered to silica-carbonate rock, which contains many of the quicksilver ore bodies. Slightly tilted andesitic flows and tuffs, tentatively correlated with the Sonoma volcanics of Pliocene age, cap the highest parts of the main range. A long belt containing steam vents and hot springs, including The Geysers, extends nearly parallel to the strike of the sediments and the serpentine bodies.

Rocks

Franciscan Group

The Franciscan group occupies about three-fourths of the mapped area. It consists mostly of sandstone interbedded with relatively small amounts of shale and conglomerate, but in parts of the area altered mafic igneous rocks, generally termed greenstone, predominate. Thin-bedded chert accompanies the greenstone in many places, although in some places it appears to be isolated in the sandstone. Metamorphic rocks, usually grouped under the term "glaucophane schists" but including other varieties, occur as relatively small bodies within the area mapped as Franciscan. A few of these are indicated on the geologic map, and there are many others too small to depict.

The Franciscan group has an apparent thickness of at least 30,000 feet, and although it is cut by many wide zones of shearing, it does not seem to have been duplicated either by faulting or by isoclinal folding. Neither the stratigraphic top nor the base of the group is exposed. Despite the great thickness of the group, the only lithologic units large enough to be mapped separately from the main bulk of the sandstone are certain extraordinarily massive and persistent flows of greenstone and some thick lenses of chert.

Sandstone. The sandstone of the Franciscan group shows considerable variation, partly original and partly due to differing degrees of induration and local mild metamorphism. The typical sandstone is hard, medium- to fine-grained, gray or grayish-green where fresh but weathering buff, and with little evidence of bedding. It consists of abundant feldspar fragments, fragments of mafic lava, various ferromagnesian minerals more or less altered to chlorite, small fragments of carbonized wood, and relatively little quartz. Locally the sandstones contain thin interbeds of shale, or more commonly flakes of shale which serve to mark the bedding. Discontinuous veinlets of quartz, and of carbonates are common, and veinlets of sodic plagioclase occur more rarely.

Shale. Shale, other than as thin beds with sandstone, appears to be very scarce. It is gray or black, and in most places it is crumpled. Much of it is apparently composed of minute clastic fragments of the same minerals as in the sandstone rather than of clay minerals.

Conglomerate. Conglomerate is sparsely distributed throughout the sandstone, and no persistent beds of it were recognized. The pebbles of the conglomerate are well rounded and rarely exceed 6 inches in diameter. They consist in part of Franciscan rocks, but chiefly of foreign rocks such as quartzite, silicified rhyolite, quartz porphyry, and black chert.

Greenstone and Chert. The greenstone in the Franciscan group occurs as several large bodies, shown in plate 29, and some smaller unmapped lenses. In some places, for example southeast of Pine Flat, the greenstone forms precipitous cliffs; elsewhere, for example north of The Geysers, it is so crumbly that its presence is revealed only by fragments in the soil. Most, if not all, the greenstone bodies consist either of surface flows or of pyroclastic rocks. Although they are nearly all fairly mafic, their composition and texture vary, and for that reason the macroscopic features of the rocks of several extensive areas are described in some detail.

The elongate lens that extends from Pine Flat for 5 miles to the southeast consists of aphanitic pillow basalt. The outcrops of this rock are deep brown in color, and are knobby because of the well-developed pillow structure. The pillows are from one to three feet in diameter. In a few places their margins are composed of altered palagonite, but generally the rock is so altered that it is not possible to distinguish glassy rims. Locally a gradation in texture from aphanitic borders to fine-grained centers can be observed. Most of the pillows are tightly packed, but between some are thin contorted lenses of chert. Thicker layers of chert separate what are probably individual flows.

The large mass that makes up Black Mountain and extends northwestward to form Sulphur Peak contains other types of greenstone,

but this mass is poorly exposed and is possibly in part intrusive. Its northeastern or upper part consists of a resistant agglomerate, apparently somewhat more siliceous than basalt, underlain by deep-brown fine-grained tuffs interbedded with light-colored but locally iron-stained siliceous rocks that are probably silicified tuffs. The southern or lower part of the mass is diabasic, but it locally contains coarse gabbro, which may be intrusive into the lava.

The greenstone extending from the vicinity of the Socrates mine northwestward beyond the Cloverdale mine consists mostly of vesicular or amygdaloidal chloritized lava; it includes some fine-grained pillow basalts and a lighter-colored rock that contains phenocrysts of orthoclase (?) up to an inch in length. This area also contains many unmapped lenses of green sandstone, and as these two rocks interfinger, the boundaries between them on plate 29 are generalized.

Some of the chert is associated with greenstone, but some of the largest chert lenses are not known to be in direct contact with greenstone. Only a few of the largest chert bodies are shown on plate 29; there are many others too small or too poorly exposed to map. At the Cloverdale, Kissack, and Buckeye mines the chert is the host rock for quicksilver ore—a relation that is exceptional in California quicksilver deposits.

The chert varies in color from nearly white to red or green or brown. Most of it is thin-bedded, one- to three-inch layers of hard chert being separated by partings of soft shale about an eighth of an inch thick. Some of the lenses are only slightly folded; others are sharply bent into small chevron folds. Possibly because of mild metamorphism, the chert is locally recrystallized. In some places the chert is massive; here the shale partings are not in evidence and have probably been silicified, and the rock has a peculiar mottled color pattern, being dominantly a brilliant orange with patches of red, yellow, blue, or white.

The more continuous lenses of chert are useful marker beds over limited areas.

Schists. Small bodies of schists and other metamorphic rocks occur along the edges of serpentine intrusions, and at some places in shear zones where there is no serpentine exposed nearby. The most common metamorphic rock contains glaucophane, and probably also lawsonite, but it is not everywhere schistose. Much of the glaucophane-lawsonite rock is demonstrably formed from rocks common in the Franciscan group—sandstone, greenstone, and chert. Among the other common metamorphic rocks are various phyllites, hornblende and pyroxene gneisses and unfoliated rocks of similar composition, and recrystallized chert. In many places the metamorphic rocks are close to serpentine bodies, but critical examination of the field evidence does not indicate that they have any direct genetic relation to serpentine.

Serpentine

Serpentine, a rock formed by deuteric hydrothermal alteration of various ultra-mafic rocks but principally from peridotite, forms half a dozen discontinuous, highly elongate bodies which extend the length of the mapped area. As elsewhere in the Coast Ranges, the serpentine is probably of Upper Jurassic age, but there is no way of closely dating it in this area.

Because of the soft and platy character of the dominant serpentine mineral, the rock yields readily to pressure, so that most of the serpentine bodies now consist of relatively small blocks of partly serpentinized peridotite engulfed in an abundant matrix of flaky serpentine. This flaky serpentine forms the narrowest bodies and the borders of the larger ones, but even the central parts of the widest bodies contain a large percentage of this plastic matrix between blocks.

The flaky serpentine is rarely exposed in the areas that contain many blocks except in steep gulches, slides, underground workings, and road cuts; but where the flaky material makes up most of the rock, it is well exposed in many places. It commonly varies in color from bright green to greenish white, but in places it is dark green. In this rock all the original igneous textures of the peridotite are destroyed, and the rock is highly foliated and generally contains numerous slightly curved shiny parting surfaces. Most of the rock is soft and soapy, but the shiny surfaces are somewhat hardened and appear to have recrystallized.

The blocks of massive serpentine, some of which are more than 10 feet in maximum dimension, are dark bluish green to greenish black on fresh surfaces but weather to reddish-yellow or reddish-brown hues. Abundant pseudomorphs of pyroxene, one eight to half an inch across, are somewhat more resistant to weathering than the serpentine derived from olivine, and impart a roughness to weathered surfaces. Networks and veinlets of chrysotile cut these rocks, particularly along the margins of the blocks. Small crystals of magnetite or chromite are scattered through most of the serpentine.

The serpentine has locally been altered to silica-carbonate rock, which is the host rock for several of the larger ore bodies; but, as the largest mine is not in silica-carbonate rock nor in serpentine, this association of serpentine with quicksilver ore bodies results from the shear zones having localized both the early serpentine intrusion and the later hydrothermal solutions and does not indicate a genetic relationship between serpentine and quicksilver.

Silica-Carbonate Rock

The term silica-carbonate rock is applied to an assemblage of silicified and carbonatized rocks, formed from serpentine by hydrothermal alteration of a far more radical character than that which changed peridotite to serpentine. As most of the ore bodies in the district are closely related to this rock, its recognition helps in prospecting. It is impossible to describe all varieties adequately, but most silica-carbonate rock has an easily recognized and distinctive appearance.

Silica-carbonate rock is somewhat more resistant to erosion than most rocks in the area, and it generally crops out in brown cavernous and pitted low knobs or irregular walls, referred to by the miners as "dikes." In outcrop the rock is generally porous and cellular, because much of its carbonate has been leached out, leaving a residual box-work of silica. Less-weathered specimens show the rock to consist mainly of chalcedony and of carbonates that range from calcite through dolomite and ankerite to magnesite. These constituents are present in highly variable proportions, and in most varieties several generations of small veins of quartz, chalcedony, or carbonates traverse the rock in various directions. Careful examination shows that much of the rock has features inherited from the more or less sheared serpentine from which it was

derived. Commonly the texture is minutely sheared and lenticular; some specimens show pseudomorphs of pyroxene crystals, and nearly all varieties contain minute black grains of magnetite or chromite. All gradations between serpentine and silica-carbonate rock can be found, but most individual bodies are sharply bounded.

Most of the silica-carbonate rock lies along the edges of serpentine intrusions, where the serpentine was more highly sheared than elsewhere and possibly offered the easiest passage to ascending solutions. The bodies located more centrally in serpentine masses can in most cases be demonstrated to lie along shear zones, so that they afford a means of following such zones through the serpentine.

The period of alteration during which the serpentine was transformed to silica-carbonate rock can not be accurately dated within the mapped area. Close to the area, however, rocks of the Sonoma volcanics are locally silicified, a fact suggesting that part, if not all, of the alteration occurred either in upper Pliocene or in post-Pliocene time. The alteration is certainly more recent than any of the major faulting, except possibly the late block faulting that lowered the Sonoma volcanic rocks to the level of the valley of Maacamas Creek.

Mafic Intrusive Rocks

Mafic rocks, apparently intruded along a contact between serpentine and greenstone, occupy a semicircular band that emerges from under the Sonoma volcanics about two miles west of Mount St. Helena and crosses the main divide three miles north of the same peak. These mafic rocks are widely varied in mineral composition, grain-size, and texture. Although they have not been studied microscopically, they appear to consist of variable portions of olivine, pyroxene, hornblende, and plagioclase. They are mostly diorites or gabbros.

Somewhat similar rocks on the south slope of Black Mountain are likewise closely related to greenstone and a narrow serpentine intrusion.

Sonoma Volcanics

Volcanic rocks which cap the highest prominences in the area are believed to be northern extensions of the Sonoma volcanics, of Pliocene age. [7]

The general concordance of the base of isolated volcanic masses suggests that they once formed an essentially continuous cover over at least the eastern half of the mapped area. The thickness of the volcanics is estimated to be more than 2,000 feet.

The dominant rock is a readily weathered light-gray hornblende biotite andesite, which occurs as flows and as the principal constituent of some tuffs. Other varieties are silicic tuffs containing numerous fragments of obsidian, an andesitic rock that contains closely packed spherulites, and, on Mount St. Helena, a light-gray rhyolite.

Much of the southern part of the area mapped as Sonoma volcanics is believed to be covered with extensive slides or mud flows, but both here and along the western margin of the mapped area downfaulted volcanic

[7] Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Acad. Sci., Proc., 4th ser., vol. 2, pp. 551-554, 1922.

Morse, R. R., and Bailey, T. L., Geological observations in the Petaluma district, California: Geol. Soc. America Bull., vol. 46, pp. 1437-1456, 1935.

Anderson, C. A., Volcanic history of the Clear Lake area, California: Geol. Soc. America Bull., vol. 47, pp. 629-664, 1936.

Johnson, F. A., Petaluma region: California Div. Mines, Bull. 118, pp. 622-627, 1943.

rocks occur in place. The volcanic rocks on the main ridges are essentially horizontal, but some of the downfaulted blocks are inclined as much as 30°.

Landslides

More than fifty landslides are shown on the geologic map (pl. 29). Nearly all have some physiographic expression, such as cirquelike heads, distorted drainage, and hummocky surfaces, and are thus easily recognized; a few relatively old ones are stagnant and can only be distinguished by reason of their abnormal overlapping on different rocks.

Most of the slides have originated in relatively large areas of serpentine and consist almost wholly of serpentine. Their recognition is essential in order to avoid useless prospecting. Other slides consist of sheared sandstone and shale of the Franciscan group. These are less easily recognized than the slides in serpentine, and except where they have overridden other kinds of rock they can be distinguished only by careful observation. Although they are small their recognition is important in detailed mapping in the vicinity of the mines. Such slides are particularly numerous along both sides of Sulphur Creek below The Geysers.

Structure

The geologic structure of the area is complex in detail, but the lack of good marker beds and the relatively poor exposures allow only its largest features to be deciphered. The predominant structural feature is a group of six nearly parallel, but somewhat sinuous and braided, northwest-trending shear zones. These extend westward beyond the limits of the mapped area, and eastward they pass under the cover of Sonoma volcanics or are cut off by a large mass of serpentine. Serpentine was intruded along some of these zones and serves to make them conspicuous, but the shear zones can generally be distinguished even where not marked by serpentine.

The Franciscan strata, which at first glance appear rather hopelessly broken and jumbled, are believed to be neither tightly folded nor cut by faults of very large displacement. Their prevailing strike is northwesterly, subparallel to the main shear zones, and they dip steeply to the northeast. They are broken by a great number of small faults into numerous blocks, ranging in diameter from hundreds of feet to less than a foot. In many adjacent blocks the beds have different attitudes, owing in part to slight folding and crumpling of the sandstone beds but probably even more to differential rotation of blocks between faults or within a matrix of black shale.

The overlying Sonoma volcanics are little deformed, but are downfaulted to the level of the Maacamas Creek valley in the southern part of the area.

Faults and Shear Zones

Some of the faults in the Franciscan group are marked only by mere cracks, others by shear zones that may attain a width of more than 1,000 feet. The larger shear zones are steep and roughly parallel to the prevailing attitude of the beds, but the smaller ones do not show such marked alignment. Most of the major zones have been intruded by serpentine, but even where that is not the case their general course can be followed, although their margins can not be located with precision.

The cracks that mark the smallest faults are in some places tight and have slickensided walls; elsewhere they are filled with veinlets of quartz or calcite. Along some of the small faults there are narrow zones filled with gouge or, less commonly, breccia. Although the small faults are best exposed in road cuts and scoured canyon floors, they cross nearly all areas of outcrops; however, because of their relative unimportance, poor exposure, and apparent lack of continuity they have not been mapped.

The major shear zones, which have been mapped and are shown on plate 29, are characteristic of the Franciscan group in many parts of the Coast Ranges and deserve special description. Similar zones in San Luis Obispo County have been well described by Eckel, Yates, and Granger [8], and most of the criteria used by those men for the recognition of the zones can be applied in the Mayacmas district.

The shear zones closely simulate, though on a gigantic scale, the filling of an ordinary fault fissure that cuts across rocks of varying competence, for they contain blocks and lenticular bodies of hard rock embedded in a more or less gouge-like matrix. The blocks consist of the harder rocks of the Franciscan group, such as indurated sandstone, chert, massive greenstone, and schist. They range in diameter from less than a foot to nearly 100 feet; most of them are at least partly rounded but some are fairly angular. The matrix, which is dominantly dark shale and light-colored disaggregated sandstone, acted as a lubricant, which coated the harder blocks and protected them from grinding and crushing but permitted them to assume a roughly parallel orientation, with their long dimensions parallel to the direction of shear.

In the field these major shear zones are not nearly as obvious as the smaller faults, and their limits are not sharply defined. The matrix, because of its unresistant nature, is rarely exposed, whereas the larger hard subrounded blocks are exceedingly prominent. The typical exposure of a well-developed shear zone is an area only slightly less resistant to erosion than the bordering rocks and containing many large boulders of dissimilar rocks resembling glacial erratics. On a slope a shear zone commonly gives rise to many small landslides. As the shear zones generally support only grass and scattered trees, they usually appear on aerial photographs as elongate light-colored areas.

Here as elsewhere in the Coast Ranges, the direction and amount of displacement along the wide shear zones can not be accurately determined, because the zones are so nearly parallel to the bedding of the Franciscan strata. In the Western Mayacmas district, the shear zones contain more shale than the intervening areas, and it seems likely that they follow relatively weak shaly parts of the tilted Franciscan group. The great width of the gouge-like zones is therefore probably due to their shaly composition, rather than to a large amount of movement.

All of the prominent shear zones are believed to have originated either during or after the tilting of the Franciscan strata and before the intrusion of the serpentine. It is not unlikely, however, that there has been minor movement along them since the serpentine was intruded. Later faults, probably of late Pliocene age, parallel to these early structures downfaulted the Sonoma volcanics against the Franciscan group.

[8] Eckel, E. B., Yates, R. G., and Granger, A. E., Quicksilver deposits in San Luis Obispo County and southwestern Monterey County, California: U. S. Geol. Survey, Bull. 922-R, pp. 533-536, 1941.

Mode of Intrusion of the Serpentine

The appearance of the serpentine has already been described, but the form of the serpentine bodies and their relation to the surrounding rocks deserve further comment. The longest continuous body within the Western Mayacmas area has a length of six miles and a maximum width of half a mile, but other bodies whose outcrops are much shorter may be even more than six miles long at depth. In both strike and dip these elongate serpentine bodies are, in general, roughly parallel to the bedding of the enclosing Franciscan strata, and thus they resemble large upended sills.

Along the immediate contacts of the serpentine, the more or less sheared Franciscan strata are in most places deformed in such a way as to seem virtually conformable to the intrusive contact. That this conformity is more apparent than real, however, is revealed by extensive mapping, which shows that nearly everywhere the serpentine masses diverge slightly in strike from the strike of the enclosing strata, and that in places they diverge markedly for distances as great as a mile. Divergences in dip, the serpentine masses being more steeply inclined than the enclosing sediments, are likewise marked in places but are of course less apparent on an areal map. In the writer's opinion, the pattern made by the serpentine on the areal geologic map of the district (pl. 29) indicates that they were intruded along a definite system of fractures which could only have originated after the tilting of the enclosing sediments. This conclusion is thought to be further strengthened by the fact that the shear zones that localized the serpentine bodies can be followed even where they contain no serpentine.

If these tabular serpentine masses, which resemble upended sills, were intruded in essentially their present positions along steep fractures that nearly parallel steeply inclined beds, they pose a problem in nomenclature. In relation to the enclosing rock they are sill-like, but in their supposed mode of intrusion they are dike-like, and might be called "pene-concordant dikes". At any rate they mark shear zones along which the ore solutions have risen.

The state of the ultramafic material at time of intrusion is in doubt. One small mass of serpentinized ultramafic rock exposed near the divide north of Mount St. Helena was obviously liquid when intruded, for it clearly shows differentiation banding. This rock, however, is partly serpentinized banded dunite quite unlike the other masses of serpentinized peridotite. The contacts of all other serpentine bodies are so sheared, and so devoid of contact phenomena, as to make it seem unlikely that the serpentine in any given place is derived from peridotite that originally came to rest at that place. It seems possible that a peridotite magma became serpentinized at depths and that the serpentine thus formed was injected in a cold condition at higher levels.

Hydrothermal Activity

The hydrothermal activity in the district has long attracted attention because of its surface manifestation at The Geysers. Since a number of geologists have pointed out the close relation, at least geographically, between this hydrothermal activity and the quicksilver deposits, it seems proper that the geologic relations should be commented upon. Before those relations can be adequately discussed, however, it is neces-

sary to describe The Geysers and other hot springs of the area in some detail. These have been closely studied by Allen and Day [9], whose analyses and descriptions, supplemented by the writer's field observations, furnish the basis of the following discussion.

The Geysers

The Geysers is the name of an area of hydrothermal activity, about 50 acres in extent, in sec. 13, T. 11 N., R. 9 W., Mount Diablo Meridian, which has been developed into a summer and health resort. The area is situated on the north side of Sulphur Creek, at an elevation of about 1500 feet, and is accessible by good roads, one of which extends 25 miles from Healdsburg and the other 18 miles from Cloverdale.

These hot springs are said to have been discovered by a party of hunters in 1846, and within a decade the hotel and baths were known throughout the country. That they should have attained such early prominence is not surprising when one realizes that the Yellowstone geyser basin was not discovered until 1870, but it is rather surprising that the name ''The Geysers'' was applied to an area that contains no geysers. In the early days the steam is said to have issued with considerable violence from small orifices, but there is no indication that true geysers—springs that intermittently throw a column of water and steam into the air—ever existed here. The hydrothermal activity is chiefly confined to a small amphitheater, which contains flowing hot springs, hot pools, and vapor vents. In 1921 the area was drilled in the hope of using the steam to generate power, and by 1925 eight steam wells were in action. The steam has not been utilized, however, and its escape from the open wells, particularly on cold moist mornings, is quite spectacular.

The amphitheater, which is floored with landslide material, is bordered on the west by a ridge of greenstone and sandstone, and on the northeast by a mass of serpentine. The landslide material consists mostly of serpentine but is underlain by sandstone and greenstone, which are locally exposed in the nearby canyons.

Hot Springs. The hot springs are all small and shallow and have a relatively small flow. Their waters have been repeatedly analyzed, and the several complete analyses given by Allen and Day [10] show that they are all characterized by the dominance of sulphate and a nearly complete absence of chloride.

In ''The Geysers'' area acid and alkaline waters emerge from adjacent springs, and although most of the springs are very hot, some are cool. The hottest springs are all acid, whereas most of the cool ones are alkaline.

The acid waters, which owe their acidity to the abundance of the SO_4 radical, contain a large amount of silica, ammonia, and magnesia, lesser amounts of lime, and very little of the alkalies. The alkaline waters are much less saturated than the acid waters. The alkalinity is due chiefly to bicarbonates of ammonium, magnesium, and calcium. The sulphate radical is practically the only one in the acid waters, but in the alkaline waters it has an equivalent value as high as or higher

[9] Allen, E. T., and Day, A. L., op. cit.
[10] Allen, E. T., and Day, A. L., op. cit., pp. 31-38.

than the sum of the radicals that are the source of the alkalinity. As compared to the acid waters, the alkaline waters contain more of the alkalies and less of the alkaline earths; the distinctive acid ions, besides sulphate, are carbonate, bicarbonate, thiosulphate, and, in some of the waters, sulphide. Some of the compositional differences can be attributed to the fact that most of the acid springs emerge through serpentinous landslide material. Allen and Day attribute the alkalinity to dilution of acid waters by ground water.

Gases. The gas escaping from the steam wells and vents is mostly steam, which in several of the wells is apparently super-heated. The following gas analyses are given by Allen and Day.[11]

Table 1—Composition of the gases at "The Geysers," California

	Total	Other gases recalculated to 100%					
	H_2O	CO_2	H_2	CH_4	N_2+A	H_2S	NH_3
Well 1	98.045	63.5	14.7	15.3	3.5	1.7	1.3
Well 2	98.686	59.1	16.4	15.8	3.7	3.2	1.8
Well 5	98.689	63.3	14.1	14.8	3.1	3.1	1.6
Well 6	98.946	62.7	14.1	14.8	3.2	3.5	1.7
Steamboat fumarole	99.202	65.2	12.3	13.8	2.7	3.6	2.4

The unusual features of these gases are the relatively high amounts of methane and hydrogen and the relatively small amounts of carbon dioxide.

Salts. Surface evaporation of the thermal waters has given rise to a number of unusual minerals, which have been studied by F. E. Wright and H. E. Merwin,[12] and more recently by M. Vonsen[13] of Petaluma. These salts are all sulphates of magnesia, ammonia, alumina, and iron. Among the minerals identified are epsomite ($MgSO_4 7H_2O$), voltaite (complex hydrous potassium iron aluminum sulphate), boussingaultite ($(NH_4)_2SO_4 MgSO_4 6H_2O$), tschermigite ($(NH_4)Al(SO_4)_2 12H_2O$), pickeringite ($MgSO_4 Al_2(SO_4) 22H_2O$), alunogen ($Al_2(SO_4) 16H_2O$), and mascagnite ($(NH_4)_2SO_4$).

Extent of the Hydrothermal Belt

The belt of present or very recent hydrothermal activity, as marked by hot springs, by springs with abundant hydrogen sulphide, and by areas of rock alteration, extends almost the entire length of the mapped area. In the Cloverdale mine there are springs giving off hydrogen sulphide, and in the Buckeye mine much carbon dioxide was encountered. From these mines, which are in the northwest corner of the district, the belt trends southeastward in a nearly straight line down the slope toward Sulphur Creek. Areas of hydrothermally altered rock and areas barren of vegetation are conspicuous between the Buckeye mine and The Geysers, and can be well observed from the Cloverdale-Geysers road. East of The Geysers, the belt trends nearly parallel to the canyon. In this part of the belt there are many mineral springs, but rock alteration is not prominent except at the Little Geysers, which are a group of hot springs and steam vents in a small amphitheater about 4 miles east of The Geysers. About a mile east of the Little Geysers the belt is lost in landslide, but its continuation is probably indicated by Castle and

[11] Allen, E. T., and Day, A. L., op. cit., Table 13, p. 76, recalculated.
[12] Published in Allen and Day, op. cit., pp. 38-45.
[13] Oral communication.

Andersons Hot Springs and other hot springs on the northeast side of the range.

The belt is very nearly parallel to one of the larger serpentine intrusions but appears to be somewhat straighter; it clearly cuts across the bedding of the Franciscan group.

Relation of Hydrothermal Activity to Igneous Rocks

No direct relation between the present hydrothermal activity and the Pliocene Sonoma volcanics can be established, because the hydrothermal belt does not cross these rocks nor contain any Pliocene dikes. Allen and Day infer that The Geysers are underlain at shallow depths by intrusive rock;[14] but the gabbro they mention as having been found while drilling one of the steam wells is almost certainly related to the greenstones of the Franciscan group, which are abundant in the vicinity. None of the most recent eruptive rocks in this part of California—which range from basalt to rhyolitic obsidian[15]—are present in the Western Mayacmas district. However, despite the lack of observed relations between the Sonoma volcanics and the recent hydrothermal activity, the composition of the gases and the abundance of heat clearly indicate that the present hydrothermal activity is related to magma at depth, even though the composition of this magma remains unknown.

Spring Deposits and Rock Alteration

Sinter deposits are comparatively scarce in the thermal belt, which, however, contains some very small areas of sinter, both calcareous and siliceous. What from a distance appear to be aprons of white sinter are areas of bleached rocks on which there is little vegetation. At The Geysers rock alteration is slight but varied. In the arkosic sandstone the feldspars are in places converted to clay minerals, though only a small part of the rock is so much altered as to have lost coherence. The serpentine boulders in the landslide are more altered, each being surrounded by a thin shell of white, porous material that appears to be mostly silica. Elsewhere in the district, both along the main belt of present hydrothermal activity and at considerable distances from it, are other areas of altered sandstone somewhat larger than The Geysers area, but the particular kind of serpentine alteration noted above was not seen beyond the limits of the belt.

Mercury was not detected in any of the spring sediments or sinters analyzed by Allen and Day, but, as they point out and as the writer has observed, cinnabar is closely associated with opal and chalcedony at some places in the hydrothermal belt. This relation is illustrated by a specimen from a small area of hot ground, locally known as Sulphur Bank, about a mile west of The Geysers. The sandstone of which the specimen consists was first partially replaced, mostly by opal but in part by chalcedony, along small sharp fractures; the unsilicified sandstone was later altered, partly to a clay mineral, and then leached so that it now has a rather moth-eaten appearance. The silicified material contains a minute amount of cinnabar, which appears to have been deposited with the silica. Until the clay mineral has been specifically identified, it is not possible to form a valid opinion as to the character of the solutions that altered the rock. It is clear, however, that the

[14] Allen and Day, op. cit., p. 14.

[15] Anderson, C. A., Volcanic history of the Clear Lake area, California: Geol. Soc. America Bull., vol. 47, pp. 629-664, 1936.

solution which deposited the silica and cinnabar differed from those which afterward caused the leaching.

Relation of Ore Solutions to Present Hydrothermal Activity

The hydrothermal activity that is now going on, at least insofar as it is expressed at the surface, differs in several respects from that which converted the serpentine to silica-carbonate rock, and from that which deposited cinnabar. The solutions issuing at present differ from the ore-depositing solutions principally in their acid character, their ammonia content, their lack of mercurial ions, and their low silica content. Their effect on the serpentine and sandstone also differs from that of the ore solutions on similar rocks. As the recent alteration can be studied over a vertical range that is roughly coextensive with the supposed range for quicksilver deposition, it seems improbable that quicksilver is now being deposited beneath the hydrothermal areas. There can be no doubt, however, that formerly, at some places along the belt in which hot solutions are now issuing, somewhat different solutions rising along the same channelways deposited at least a little cinnabar.

ORE BODIES

General Features

The quicksilver ore bodies occur where either cinnabar or native mercury, or both, have been deposited from hydrothermal solutions ascending along fractures that extend to considerable depth and are therefore in or close to, major faults or shear zones. Because many of the fault zones are partly or entirely filled with serpentine, most of the mines lie along the borders of serpentine masses in lenses of silica-carbonate rock, but as the most productive mine of the area—the Cloverdale mine—lies along a fault that contains no serpentine, it is evidently the presence of a fault, rather than of serpentine, that is essential.

Where the ore minerals were deposited in small openings, the ore bodies are classified as stockworks and irregular veins; where the ore minerals are disseminated through either sandstone or silica-carbonate rock the ore bodies are more appropriately referred to as pods, pipes, or lenses. All the ore bodies have been small, and none has been followed to a depth of more than 400 feet below the outcrop. The majority were localized by small structural features, such as splits in faults, changes in strike of a fault so as to form an inclined inverted trough, or local flattening of faults.

The grade of the ore that has been mined varies within wide limits. In 1943, ore with about 2.5 pounds of quicksilver to the ton was commercial for furnace operation, but it had to be several times as rich for retort operation. The average quicksilver content of all the ore that has been mined was probably about 7 pounds to the ton.

Reserves in known ore bodies are very small, and if the peak production of the last 20 years—about 1,000 flasks a year—is to be maintained, extensive exploration and development will be necessary. It seems unlikely that more than 1,000 flasks a year will be produced unless a price of about $200 a flask is established.

Mineralogy

The minerals closely associated with the ore bodies, whether genetically related to them or not, are listed in table 2. Cinnabar, the most

Table 2. Minerals associated with quicksilver deposits in the Western Mayacmas district, California

	Name*	Composition	Remarks
Mercury minerals	*Native mercury*	Hg	Principal ore mineral in the Socrates, Contact, and Rattlesnake mines.
	CINNABAR	HgS	Principal ore mineral of the district. Occurs in serpentine, silica-carbonate rock, sandstone, gouge, and chert.
	Metacinnabar	HgS	Occurs in the Culver-Baer mine in small amount.
	Montroydite	HgO	Probably present in minute amounts in outcrop above the Socrates mine.
	Tiemannite	$HgSe$	Said to occur in the Socrates mine.
Gangue minerals	*Quartz*	SiO_2	Veins in silica-carbonate rock; a few veins in the Socrates mine are over one foot wide.
	CHALCEDONY	SiO_2	Everywhere present in silica-carbonate rock.
	Opal	$SiO_2 . nH_2O$	Dominant mineral of the silica-carbonate rock in a fewplaces; common as late veinlets in this rock.
	Calcite	$CaCO_3$	Forms late veins in silica-carbonate rock.
	DOLOMITE	$CaCO_3 . MgCO_3$	Probably the most abundant carbonate in silica-carbonate rock.
	Ankerite	$CaCO_3 . (Mg,Fe)CO_3$	Probably common in silica-carbonate rock.
	Magnesite	$MgCO_3$	Uncommon; replaces serpentine and forms veins.
	Barite	$BaSO_4$	Small crystals in vugs in ore of Cinnabar King mine.
	Clays	Hydrous aluminum silicates	Alteration products of feldspars in sandstone at Socrates mine.
	Hydrocarbons	Compounds of C and H	Widespread, though scarce, in mines in silica-carbonate rock. Includes solids (curtisite?), tars, greases, and oils.
	Pyrite	FeS_2	Accompanies silica-carbonate rock and cinnabar in small quantity.
	Marcasite	FeS_2	In a few prospects south of Pine Mountain.
	Jarosite	$K_2Fe_6(OH)_{12}(SO_4)_4$	In a barren vein at the Cloverdale mine.
Rock minerals	QUARTZ, FELDSPARS AND CLAYS		Chief minerals of sandstone and chert. In many places unaffected by mineralizing solutions.
	Serpentine	$H_4Mg_3Si_2O_9$	Nearly everywhere converted to silica-carbonate rock before ore minerals were deposited in it.
	Magnetite, picotite, chromite	$(Fe,Mg)O . (Fe,Cr,Al)_2O_3$	Small crystals conspicuous in serpentine and silica-carbonate rock.
Secondary minerals	Cinnabar	HgS	Some country rock contains a little painty cinnabar, which appears to be of secondary origin.
	LIMONITE	$Fe_2O_3 . nH_2O$	Abundant in weathered outcrops of silica-carbonate rock.
	OPAL	$SiO_2 . nH_2O$	Crusts on silica-carbonate rock.
	Aragonite	$CaCO_3$	Small crystals in vugs in silica-carbonate rock.
	Gypsum	$CaSO_4 . 2H_2O$	Formed by action of sulphate waters on various rocks and ores; commonly encrust mine walls or form stalactites hanging from backs of workings.
	Melanterite	$FeSO_4 . 7H_2O$	
	Epsomite	$MgSO_4 . 7H_2O$	

* Capitals indicate mineral is abundant or widespread. Italics indicate mineral is moderately abundant or widespread. Lower case, not italicized, indicates mineral is of rare occurrence in the district.

abundant ore mineral, occurs as incrustations, fracture-fillings, and less commonly as disseminated crystals formed by replacement. Native mercury, which is also of economic importance in this district, occurs in vugs in veins cutting silica-carbonate rock, and fills pores in sandstone; and in a few places it almost fills minute fractures, forming liquid veinlets. Any other quicksilver minerals that may be present are so scarce as to be of no commercial importance.

Of the gangue minerals only a few deserve special comment. Chalcedony is the most abundant mineral in the silica-carbonate rock generally, but the ore seems to be chiefly associated with rock rich in carbonates. Clay minerals are not particularly abundant in any of the mines except those that are in chert, which has partings of clay shale. Hydrocarbons, though nowhere abundant, are present in most of the mines in silica-carbonate rock: they were deposited, in part at least, contemporaneously with the cinnabar and before the latest quartz. Pyrite is on the whole rather scarce, and is nowhere so abundant as to occasion any special difficulties in furnace treatment.

General Distribution

All the ore bodies in the Western Mayacmas district are confined to a relatively narrow belt, which extends from the Cloverdale mine at the west through Pine Mountain at the east. Several large mines in the Eastern Mayacmas district lie on the eastward continuation of this belt. Scattered occurrences of cinnabar have been prospected on both sides of the belt, but although there is evidence of extensive hydrothermal activity at some of these occurrences, no sizeable ore bodies have been found.

The distribution of the cinnabar and native mercury is controlled by a few sinuous shear zones, which in most places contain serpentine intrusions. Where hydrothermal solutions made their way upward through serpentine masses or along their borders, the serpentine was converted to silica-carbonate rock, and most of the ore bodies formed on the borders of serpentine intrusions are in silica-carbonate rock. Where serpentine does not fill the shear zones, rocks other than silica-carbonate rock may act as hosts for quicksilver minerals. At the Cloverdale mine the host rock is chert, and at the Rattlesnake mine it is sandstone and shale, silica-carbonate rock being absent at both mines. At the Socrates mine ore was probably more abundant in sandstone than in the adjacent silica-carbonate rock. The Sonoma volcanics are not known to contain quicksilver minerals at any place in the area.

Character and Localization

The ore bodies were mostly formed by the filling of fractures or pore spaces with cinnabar or native mercury, but in some places the country rock was partly replaced by cinnabar and the grade of the ore was correspondingly heightened. Where the ore minerals were deposited in small fractures, the ore bodies may be referred to as stockworks or as irregular veins, but where the minerals were deposited in pore spaces or as disseminated crystals the bodies are more properly termed lenses, pods, or pipes. Some of the ore bodies fall definitely within one or the other of these groups, but most of them have a composite character. In form and character, however, all the deposits are broadly similar, and all consist of small amounts of ore minerals scattered through the gangue and country rock as distinct crystals, globules, clots, or small veinlets.

Since openings, either pore spaces or fractures, are necessary for the localization of quicksilver ore bodies most of the ore is in brittle rocks such as chert or silica-carbonate rock, but other conditions must also be fulfilled if the ore minerals are to be deposited in abundance. Some of these conditions are physico-chemical, being related to temperature, pressure, and solubility, but these conditions must be judged by their effects, which are not well enough understood to be of value in mining or prospecting. Other necessary conditions are largely structural, and these, because they lend themselves to direct study, are of value in finding and following ore bodies. Faults have been especially influential. Most of the ore is localized by inclined faults that are filled with gouge or shale or have a hanging wall of serpentine, but even beneath such faults ore bodies occur only in favorable places. These favorable places are where the fault bends in such a way as to form an inclined inverted trough, where the fault is exceptionally flat, where a series of closely spaced vertical tension fractures underlies the fault, or where two faults meet at an acute angle. In some places, for example at the Cloverdale mine, depositional contacts may act in the same fashion as gouge-lined faults.

Size

The ore bodies differ in size, partly because they were formed in different geologic settings and in different kinds of rock, and partly because the cut-off grade of minable ore differed according to circumstances. The largest ore bodies were those in chert at the Cloverdale mine; these were cheaply mined in glory holes and followed downward in stopes. One which was mined to a depth of 100 feet was a continuous shoot nearly 300 feet long and perhaps 20 feet wide; others in the same mine, though containing no single shoot as continuous as this, were considerably larger in the aggregate. At the Socrates mine the largest stope was in a shoot that extended almost continuously down a contact between silica-carbonate rock and sandstone to a depth of 400 feet; this shoot was 70 feet long and about 15 feet wide. In the Culver-Baer mine the largest accessible stope, entirely in silica-carbonate rock, is 125 feet long, 20 feet wide, and about 50 feet high.

Outlook for the District

In this district as in most quicksilver districts, reserves actually blocked out and ready for mining at any given time are very small. The graph showing the past production of the mines of the district (fig. 2) reveals a number of salient facts that bear on the probable future production.

1. Although there has been a considerable amount of surface and near-surface prospecting in the area, nearly all the production has come from four mines. 2. At least four times mining has nearly or entirely ceased, but each time it has been revived by the stimulus of higher prices. 3. During the revival in the early 1930's, the area yielded an annual production of less than 1000 flasks even though quicksilver prices were around $120 a flask—a price nearly equivalent, if changing economic conditions are taken into account, to a price of about $190 a flask in 1942. 4. The recent production, stimulated by high prices, is about the same rate.

These facts indicate that at the expectable rate of exploration and mining, and with a price of about $200 a flask, the district will produce

about 1000 flasks a year, though the geologic conditions in a few of the mines indicate that the production may be less than 1000 flasks. With lower prices only small-scale retorting of pockets of high-grade ore is profitable; such activity will probably continue to yield between 100 and 200 flasks of quicksilver a year.

As most of the more favorable areas have been carefully examined, it seems unlikely that new ore bodies of appreciable size will be found on the surface. It is quite possible, however, that new ore shoots will be found by additional underground exploration, and that some of the mined shoots will be found to extend below the depths at which they were abandoned. Several places that seem favorable for further exploration are mentioned under descriptions of the individual mines.

Suggestions for Prospecting

The district has been pretty thoroughly prospected, and much of this work has been done intelligently, but, since many of the ore bodies that have been mined were inconspicuous on the surface, it is not unreasonable to hope that new ore bodies may still be discovered by surface prospecting. The most favorable places are in silica-carbonate rock and in the wide shear zone shown on plate 29. When prospecting in silica-carbonate rock, particular attention should be paid to places where the hanging wall has a rather gentle dip, where it bends sharply toward the footwall side, and where there are many cross fractures. When prospecting in sandstone in the shear zones, particular attention should be paid to areas of veined, iron-stained, and otherwise altered rocks.

More specific suggestions for further exploration are made in the descriptions of individual mines.

MINES AND PROSPECTS

The mines and prospects of the Western Mayacmas district have been divided for easy reference into three geographic groups, each of which has, also, some distinctive geologic features. The groups are, from west to east: (1) properties north of Sulphur Creek, (2) properties on the ridge between Sulphur and Little Sulphur Creeks, and (3) properties at Pine Flat and farther east. The groups and the properties in each group are described in west-east order.

Mines North of Sulphur Creek

The mines north of Sulphur Creek are all in chert of the Franciscan group, and in all of them the principal ore mineral is cinnabar. They include the Cloverdale mine, which has yielded over 16,000 flasks, and the Kissack and Buckeye properties, which have made only a small production.

Cloverdale Mine

The Cloverdale mine, the most productive in the district, is in sec. 4, T. 11 N., R. 9 W., near the junction of Sulphur Creek and Squaw Creek but high on the steep intervening ridge. The property consists of several claims owned by J. E. Schor, Andrew Rocca, and Joseph Garcia; in 1943 it was leased to John A. McDonald of San Francisco.

Although the ores were first discovered in 1863, the first recorded production was in 1875, and by 1943 over 16,000 flasks had been recovered. As shown by figure 2, which gives the recorded annual production,

the mine has been more continuously operated than any other in the district, but it has been comparatively inactive since the late 1930's. In 1943 a small open cut southeast of the main working yielded 49 flasks, but in 1944 the property was idle.

Mining was carried on in several glory holes and in many small stopes that were reached through an intricate network of about 10,000 feet of adits and drifts (see pl. 30). All of the underground workings except the No. 5 level were inaccessible in 1943, and the following description is therefore in a large degree based on maps furnished by the lessee in 1943, on published records of the geology[16], and on information given by miners who worked in the now inaccessible levels. All existing maps of the workings show discrepancies in detail, but the positions of most of the geologic contacts as shown on several maps are in fairly close agreement.

The larger ore bodies were in two layers of chert (see pls. 29, 30). The upper layer is crenulate, but in general it strikes northwestward and dips northeast, into the hill, at moderately steep angles; the lower layer strikes east and stands nearly vertical. A steep fault or fault zone,

[16] Schuette, C. N., Occurrence of quicksilver ore bodies: Am. Inst. Min. Met. Eng., Tech. Pub. No. 335, pp. 28-30, 1930.

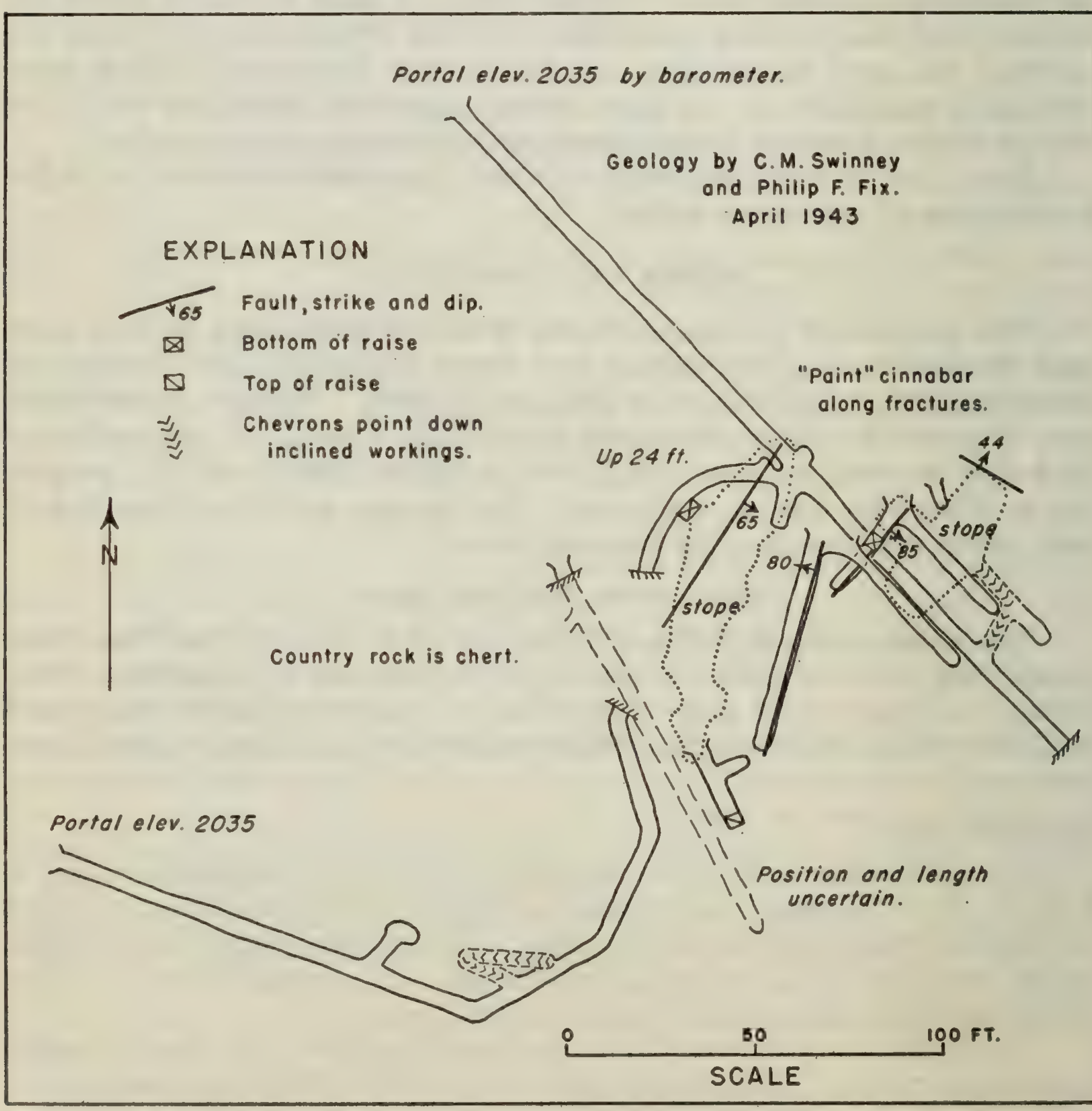

FIG. 3. Geologic map of the Buckeye quicksilver mine, Sonoma County, California.

nowhere well exposed at the surface, is believed to separate the chert layers. Sandstone and shale of the Franciscan group overlie the upper chert layer, and the intervening contact, though only locally faulted, has been termed the "hanging-wall fault" and has been closely followed in mining. Each of the chert layers is underlain by greenstone, which, as it shows pillow structure in places and consequently must be extrusive, can not be genetically related to the ore bodies.

The chief ore mineral is cinnabar, which occurs along fractures in the more broken chert and only very locally replaces the chert; a very little native mercury also has been observed. The positions of the ore shoots are apparently influenced by several conditions. One is lithology; in each chert layer a particularly massive bed from 6 to 12 feet thick, without the usual shale partings, contains most of the ore. Other controlling features are structural. In the upper chert body ore was found close beneath the "hanging-wall fault" on a well-developed anticlinal nose, and at other places beneath the same contact where it was exceptionally flat or locally rolled to reverse dips. In the nearly vertical lower chert body, particularly rich ore is said to have been mined in the Cassin and Britton workings, where no clear-cut localizing structure except the nearby fault is apparent.

The chert has probably been sufficiently explored above the No. 5 level, but the upper chert layer from this level downward is worthy of more exploration. An anticlinal roll that pitches downward from a stope above the No. 5 level could be explored by continuing the No. 5 adit straight from the portal to the "hanging-wall fault".

Kissack Prospect

The Kissack prospect, formerly known as the Squaw, as the Big Chief, and as the Amazon, is in sec. 4, T. 11 N., R. 9 W., between the Cloverdale and Buckeye mines. The property is owned by L. D. Kissack and in 1943 was leased by E. E. McPherson. It was inactive in 1943, and its only recorded production, made between 1930 and 1940, is very small. The workings consist of a short adit and several open cuts in chert.

Buckeye Mine

The Buckeye quicksilver mine, which is in secs. 3 and 4, T. 11 N., R. 9 W., about half a mile east of the Cloverdale mine, is owned by Carl A. Baumeister of Healdsburg, and was leased in 1943 to Elmer Landrebe of Cloverdale. It was first worked in 1864, but its total recorded production, which resulted from intermittent operations between 1916 and 1942, is 40 flasks. The exploratory work in progress in 1943 had apparently been abandoned early in 1944. Equipment on the property includes a two-pipe retort and an aerial tram leading to an ore bin at the Cloverdale mine.

About 900 feet of accessible workings, and perhaps 150 feet of inaccessible workings, explore a northeastward-dipping lens of contorted chert (see fig. 3). The lens is about on the strike of the chert layers at the Cloverdale mine, but it is impossible to trace outcrops continuously between the two mines. Cinnabar occurs sparingly as painty to finely crystalline crusts in fractures cutting unusually massive beds of chert. The ore bodies appear to have been localized beneath small faults, which have hanging walls of chert that contains abundant shale partings.

Mines on Ridge Between Sulphur and Little Sulphur Creeks

The ridge between Sulphur Creek and Little Sulphur Creek contains ore bodies in silica-carbonate rock and in sandstone close to silica-carbonate lenses. Most of the mines contain appreciable amounts of native mercury. The Culver-Baer, Socrates, and Contact mines have been the large producers, but several smaller mines have yielded rich ore.

Esperanza Mine

The Esperanza mine, known prior to 1918 as the Bright Hope mine, is in sec. 10, T. 11 N., R. 9 W., about two miles west of The Geysers. It is owned by James G. Cortelyou of Cloverdale, and in 1942 it was leased to John W. Sutherland of Chicago, Illinois, and John F. Rogers of Cloverdale. Its earliest recorded production was made in 1917, and its total production, from intermittent operations, is about 200 flasks.

About 10 adits of various lengths have been driven through sandstone toward a thin lens of serpentine that is locally altered to silica-carbonate rock. Only two of these adits were open in 1943, and neither had reached the ledge. Both were in mashed sandstone and shale, which in places contained cinnabar in fractures and as disseminated grains, and more locally some native mercury. Very good ore is said to have been found in the silica-carbonate rock and in the sandstone footwall. The lens of serpentine and silica-carbonate rock is very small where exposed at the surface, but it is impossible to judge the possibilities of the mine from the limited open workings.

Dewey's Mine

The Wild Hog, Eagle Rock, Big Red, and Cima workings, in sec. 14, T. 11 N., R. 9 W., had been leased in 1944 by Frank A. Dewey from The Geysers Development Company. The properties lie along a northwest-trending zone on the south side of the Cloverdale-Geysers road. Prior to 1944 the ore from the workings had been retorted, but in that year a rotary furnace of about 20 tons daily capacity was being installed. Prospecting in the area began in 1940 or 1941, and the mine is still in the development stage, but it has yielded almost 100 flasks from retorts.

The workings consist of several short adits, totaling about 600 feet, and small open cuts scattered over an area about 4000 feet long. These workings lie on the northern edge of a wide shear zone intruded by thin lenses of serpentine, which is altered in places to silica-carbonate rock. Cinnabar and a little native mercury have been found at several places in the sandstone near the serpentine, and smaller quantities of both have been found in the silica-carbonate rock. The ore bodies so far encountered have been small, but so rich and so closely spaced as to encourage further prospecting and development.

Black Bear Mine

The Black Bear mine, formerly known as the Kentuck or Kentucky mine, is in sec. 22, T. 11 N., R. 9 W., about a mile northwest of the Culver-Baer mine and on the continuation of the same ledge. It is owned by the Black Bear Mining Corporation, of which Charles Humbert of Cloverdale is president, and in 1943 it was leased by Raymond Guyer of Mill Valley, California. Although the mine is said to have been opened in the 1870's, the only quantitative statement on record as to its output is one made by Becker,[17] who in 1888 credited the mine with

[17] Becker, G. F., Quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, pp. 377, 1888.

a production of 54 flasks. It is also recorded that in 1900 some ore from the Black Bear mine was treated in the Culver-Baer furnace.

About 700 feet of workings, including two nearly parallel adits 250 and 280 feet long, were accessible in 1943, and the caved workings were said to be about 500 feet in extent. The open adits nearly cross a narrow serpentine intrusion, which trends northwestward and dips northeast. Irregular parts of the serpentine have been converted to silica-carbonate rock and later broken by small transverse tension fractures, which locally contain cinnabar. A single small stope and a short inclined shaft indicate that the cinnabar was mostly concentrated near a sandstone hanging wall.

Continued exploration in the vicinity of the present workings does not appear justified by the present showings, but the hard rib of silica-carbonate rock to the southeast may warrant further investigation.

Culver-Baer Mine

The Culver-Baer mine is in secs. 23, 24, and 25, T. 11 N., R. 9 W., at the head of the North Fork of Little Sulphur Creek, which flows in what is sometimes referred to as Devils Den Canyon. From Healdsburg it is reached by traveling 21 miles along the county road that leads to The Geysers.

The property, which consists of seven patented claims, is owned by the Culver-Baer Mining Company of Cloverdale, and in 1943 it was leased to Mr. Carl A. Baumeister. The present holdings include the former Lost Ledge or Oakland mine and the Geyser, Missouri, and Clyde mines, all probably located and first mined in 1872. Only the ground of the old Geyser mine was being worked in 1943, but in 1944 some rich ore was mined from near the surface close to the upper portal of the old Oakland workings. Reduction equipment on the property includes a 20-ton rotary furnace and a 2-pipe retort.

Production between 1874 and 1880, largely from the old Oakland mine but in part from the Geyser mine, amounted to about 8,500 flasks, and since 1880 intermittent operations have yielded 3,000 flasks. Of the 8,000 feet or more of workings, only about half were accessible for examination in 1941-43 (see pl. 31). These accessible workings included not only the recent work but also parts of the old Oakland and Geyser mines; the most productive parts of the Oakland mine, however, and all those of the Missouri and Clyde mines, were inaccessible. Probably no geologic maps of these inaccessible workings were ever made, but plate 31 shows the position and approximate size of the major stopes as remembered by miners.

The workings of all these mines except the Missouri explore an irregular elongate body of serpentine, which is locally converted to silica-carbonate rock. The serpentine body extends a mile westward to the Black Bear mine and several miles eastward to the Eureka, Socrates, and several smaller mines, although in that direction it is not everywhere exposed at the surface. Its width varies, but averages at least 250 feet in the vicinity of the 1943 workings. The serpentine was emplaced along a wide shear zone and encloses longitudinal sheets of sandstone.

The only commercially important ore mineral seen in the property is cinnabar, but native mercury and metacinnabar are reliably reported to have been found in the Oakland workings. In the western part of the accessible workings the cinnabar occurs in small veinlets, usually with

quartz, or as painty films. In the rich Oakland stopes cinnabar and metacinnabar are said to have been disseminated through silica-carbonate rock, and the 1944 work in the Oakland exposed very rich disseminated ore. Unusual acicular and prismatic crystals of cinnabar, up to half an inch in length, line quartz veins in the vicinity of the Davy workings (pl. 31, altitude 2,139 feet), and in the western Baumeister stope the cinnabar was dominantly acicular. In the Missouri area, to the southeast, some native mercury has been found. Pyrite, yellow solid hydrocarbons, and oily hydrocarbons occur with the ore but are nowhere abundant. A yellow-green mineral, as yet undetermined, is closely associated with the cinnabar.

All the ore appears to have been in silica-carbonate rock. The structural controls for the ore bodies are imperfectly known, because the larger stopes are inaccessible, although in the accessible workings, as shown by the block diagram (pl. 31), several structures have influenced the localization of the cinnabar. In the higher open levels, good ore was mined from immediately beneath a relatively flat domed fault underlain by silica-carbonate rock and overlain by sandstone, but limited exploration at greater depth, where the fault is somewhat steeper, failed to find ore. Some of the ore bodies are related to minor faults, generally trending northwestward and dipping about 45° NE, that are entirely in serpentine and silica-carbonate rock. Ore bodies occur in silica-carbonate rock beneath these faults, where the footwall is cut by steep north-trending fractures which do not cross the northeast-dipping faults into the overlying serpentine. The ore body mined in the Daylight stope extended along a fault dipping 65° NE, which was joined by a large number of steep north-trending fractures. Similar steep fractures containing quartz and cinnabar are numerous in several places along the outcrop of the silica-carbonate rib, but where they are not overlain by faults, the cinnabar is too scattered to form ore.

The mining that was being done in April 1943 consisted mostly in stripping ore left along the margins of old stopes on the upper levels near the furnace. Such work can not be expected to yield more than 200 flasks of quicksilver a year. New ore shoots might be developed, however, by a more farsighted mining program, directed primarily toward thorough exploration of the silica-carbonate rock. Because the silica-carbonate body that contains the productive stopes of the Oakland workings is covered with slide for much of its length, and because of the peculiar way in which the long lowest adit was driven, a block of silica-carbonate rock some 600 feet long between the Daylight stope and the adit at the head of the furnace bin remains unexplored. This ground is favorably situated both from a mining and from a geologic viewpoint, and is worthy of exploration. Without maps or accessible workings it is impossible to determine what areas in the old Oakland workings ought to be further explored. The work that was done there encountered the largest and richest ore bodies yet found in the mine, and the best chances for finding large rich ore bodies appear to lie in that area, but exploration will of necessity have to be "blind."

Rattlesnake Mine

The Rattlesnake mine, in sec. 31, T. 11 N., R. 8 W., has been inactive for several years and all its workings are caved. Early records are vague, but in 1874 [18] and 1875 about 100 men working on the property are said

[18] The Rattlesnake mine: Mining & Scientific Press, v. 29, July 25, 1874, p. 54; v. 29, Nov. 21, 1874, p. 322.

to have recovered 65 flasks with a 15-ton Luckhardt furnace. There is no record of later activity except in 1916-1918, when only a few flasks were recovered. The workings consisted of two levels, one about 60 feet below the other and each at least 200 feet long. A winze extended from the upper level to the lower one and possibly continued to greater depth. The ore consisted of native mercury disseminated through sandstone and gouge and was accompanied by an oily hydrocarbon. As can be seen on plate 29, the mine was close to the south edge of a major shear zone, but the recorded lengths of the adits indicate that they probably never extended into this zone. Now that a safe method for working ores containing native mercury has been developed, the reopening of the mine may be justified.

Eureka Mine

The Eureka mine, first located in 1860 as the Eureka and known for a time prior to 1903 as the Flagstaff mine, is in sec. 32, T. 11 N., R. 8 W., about half a mile northwest of the Socrates mine. It is owned by Mrs. F. M. White of Oakland, California, and was leased by the Contact Quicksilver Company in the spring of 1943. At that time the road to the mine was in poor condition and there was no reduction equipment on the property. Some work done in 1904, 1914, and 1916 yielded a total of only 18 flasks of quicksilver, but a small amount of quicksilver was probably recovered during development in the early 1870's.

In the spring of 1943 the workings were inaccessible. They are reported [19] to consist of an adit more than 300 feet long with at least 350 feet of drifts along the silica-carbonate ledge, and several shorter adits and a shaft higher on the hill. A raise along the ledge is said to have been run from the lower adit to one of these shorter adits.

The Eureka mine is on the same serpentine body as the Socrates mine and is in a similar geologic setting, the ore being in a narrow lens of silica-carbonate rock dipping steeply southward into the hill, with a serpentine hanging wall and a sandstone footwall. Outcrops of the silica-carbonate rock contain cinnabar and native mercury associated with veins of quartz and carbonates. A green oily hydrocarbon and a black solid hydrocarbon accompany the ore, but they apparently bear no direct relation to the localization of the quicksilver minerals. An area of somewhat bleached sandstone below the lower adit is said to contain cinnabar and metacinnabar, but this report was not confirmed.

Visible reserves are exceedingly small, and the mine has a poor production record. The silica-carbonate lens, however, has not been adequately explored, and the similarity of the geologic setting to that of the Socrates mine suggests that further exploration along the contact between silica-carbonate rock and sandstone on the higher levels may be warranted.

Socrates Mine

The Socrates mine, formerly known as the Pioneer, is in secs. 32 and 33, T. 11 N., R. 8 W., about 2 miles north of Pine Flat, near the top of the ridge between Sulphur and Little Sulphur creeks. As early as 1860 it was operated as the Pioneer mine by Emerson & Wattles Company, and apparently in 1900 its name was changed to the Socrates mine. The

[19] Forstner, Wm., The quicksilver resources of California: California Min. Bur. Bull. 27, pp. 106-108, 1907.
Bradley, W. W., The quicksilver resources of California: California Min. Bur. Bull. 78, pp. 187, 1918.

property, which consists of one large claim and a fraction, was owned in 1943 by the Socrates Consolidated Mining Company of San Francisco, and was leased to the Contact Quicksilver Company of Oakland, California.

The mine is said to have yielded about 1,000 flasks of quicksilver between 1861 and 1900, and from that period to the end of 1936 it made a recorded production of 3,724 flasks. During 1941 and 1942, lessees produced 910 flasks so that the total production has probably exceeded 5,500 flasks.

The ore was being treated in a 30-ton Scott rotary furnace, which was on the Contact mine property, about two miles by graded road from the Socrates mine.

The Socrates mine contains about 6000 feet of workings, including four main drifts and several sub-levels reached through three adits (see pl. 32). All the workings above the 300 level, and parts of this level, were inaccessible in 1943. Plate 32 shows the geology of the inaccessible levels as mapped by Wm. Forstner in the early 1900's, as well as the new workings driven by the present lessee.

The workings explore the sheared northern contact of a serpentine body that cuts sandstone of the Franciscan group. Near the surface the contact dips 55° to the southwest, but at a depth of about 400 feet the contact is nearly vertical and locally dips to the northeast. Hydrothermal solutions rising along the contact have altered the sandstone in places, have converted the more sheared serpentine to soft silica-carbonate rock, have filled fractures with carbonates, quartz, and chalcedony, and have deposited native mercury, cinnabar, and small amounts of pyrite and hydrocarbons.

The ore bodies occur along and beneath the contact, where native mercury is especially abundant in cracks and fissures in silica-carbonate rock or gouge and is also disseminated in the sandstone. The mercury is nearly everywhere accompanied by more or less cinnabar. Two main ore shoots and several smaller pockets have been mined. One of the main shoots, mined in the "air shaft", "sandstone", 355, and 505 stopes, extended from the surface to a depth of at least 400 feet; its average length was about 70 feet and it was mined over widths that locally exceeded 15 feet but averaged considerably less. The second main shoot, mined in the Breene, Roberts, and 350 No. 2 stopes, appears to finger out at depth. Near the surface it had a length of 160 feet, and it extended downward at least 250 feet. Both these shoots appear to have been localized beneath minor rolls in the main fault, at places where branch faults diverge into the footwall.

As the known ore shoots presumably do not extend much deeper than the stopes, the best chance for finding new ore probably lies in following the main contact southeastward along the strike on or above the 300 level.

Contact Mine

The Contact mine, also known as the Walker mine and the Queen group of the Crown Point Mining Company, is in sec. 5, T. 10 N., R. 8 W., near the crest of the south slope of the divide between Pine Flat and Sulphur Creek. It is served by a good road extending from Healdsburg.

In 1943 the mine was owned by the Contact Mining Company of Santa Rosa and was leased to the Contact Quicksilver Company of Oak-

land. This company began operations in January 1941 but abandoned the mine a year later; in 1943, however, they were using the furnace and camp facilities in connection with their operation of the Socrates mine. Early records are vague, and no production prior to 1932 is recorded. During that year 80 flasks of quicksilver was recovered from the west stope, but work in the following four years yielded only 16 flasks. Between 1938 and 1940, about 325 flasks was recovered by H. G. Walker, and the Contact Quicksilver Company reported a production of 544 flasks. The known production of the mine to the end of 1942 was therefore 965 flasks.

The workings explore a north-dipping sheared contact between serpentine and sandstone along which local bodies of silica-carbonate rock have been formed (see pl. 33). The contact has been followed for about 500 feet along the strike, and an inclined winze reaches a depth of about 300 feet below the outcrop. Most of the ore came from two stopes referred to as the ''east stope'' and the ''west stope''.

The ore contains significant amounts of both cinnabar and native mercury in silica-carbonate rock, sandstone, and locally even in serpentine. The silica-carbonate ore contains chiefly cinnabar, in part filling fractures and vugs but also replacing the silicified rock, and black solid hydrocarbons fill vugs in quartz and calcite veins in this type of ore. The sandstone ore consists of sheared sandstone with shreds of serpentine, and contains disseminated native mercury in pores and in vugs in carbonate veins. The sandstone ore also contains some sharp crystals of cinnabar indicating that the native mercury has not formed in place from alteration of cinnabar.

The east stope extends from the east drift up a 45° slope for a little more than 150 feet. The ore is of the silica-carbonate type and is doubtless localized by a sharp roll in the footwall fault. Beneath a particular flat part of this ''inverted trough'' silica-carbonate rock formed, and, as it was later broken by transverse fractures, it formed an ideal locus for cinnabar deposition.

The ore body mined in the west stope is less sharply defined. In a general way, it extended down the west side of the winze (see pl. 33) to the 320-foot level, a distance of about 200 feet. The ore was of the silica-carbonate type near the surface, but at greater depth the sandstone variety containing native mercury predominated. Along the contact lay a vein, 1 to 4 inches wide, of nearly pure cinnabar. The conditions responsible for the localization of this ore shoot are vague, but the shoot appears to be related to a bend and ''flat'' in the main footwall fault.

The mine may be exhausted. The east ore shoot, however, appears not to have been adequately explored below the main haulage level, and, although the small size of the serpentine outcrop suggests that additional exploration would not be justified, it is possible that mineralization extends along the fault zone beyond the limits of the serpentine.

Mines at Pine Flat and Farther East

Near Pine Flat are a number of mines that were first located at least as early as 1864 and developed in the early 1870's. These mines are now abandoned and mostly caved. There is probably no complete record of their production, but it seems unlikely that any one of them produced a significant amount of quicksilver. Many of the mines have changed hands several times, or have been regrouped in different ways and given

various names; the former names insofar as known are recorded in the following descriptions. All the mines are in silica-carbonate lenses, and many contained native mercury as well as cinnabar.

Crystal Mine

The Crystal mine, formerly known as the Pacific, Red Cloud, and Abbey, is mostly in secs. 5 and 6, T. 10 N., R. 8 W., about 2½ miles northwest of Pine Flat. It is owned by H. A. Samson of Healdsburg, California. Although the mine was known before 1877, no production has been recorded, and in 1943 the property was idle.

The workings explore several silica-carbonate lenses formed in the serpentine body that extends from the Missouri claim of the Culver-Baer mine to the Sonoma group of mines (pl. 29). Cinnabar was seen only in the southernmost lens of silica-carbonate rock, close to the sandstone and black shale of the main footwall of the serpentine. About 600 feet of workings were open for examination, and there are inaccessible workings totalling at least 1400 feet. Extensive exploration along the serpentine contact has not revealed any sizeable ore bodies, and in spite of the abundance of silica-carbonate rock the chances of finding ore appear to be small.

Sonoma Group

The Sonoma group consists of several claims, known at various times as the Crown Point, Sonoma Consolidated, Old Sonoma, and New Sonoma, all lying a short distance north of Pine Flat, in sec. 5, T. 10 N., R. 8 W. The property, which is owned by Lee Toland, was idle in 1943. Production records indicate a yield of more than 100 flasks since 1873, and it is possible that considerable production is unrecorded.

The ore minerals were cinnabar and native mercury, which occurred in silica-carbonate rock and perhaps also in the adjacent sandstone. The accessible workings consist of two adits, whose total length is 115 feet, and several small open cuts; the inaccessible workings, according to the available maps and records, have a total length of 1000 feet. The property cannot be fairly judged from what can be seen in the workings, but only scattered crystals of cinnabar were noted in the silica-carbonate outcrops in its vicinity.

Anne Belcher Mine

The Anne Belcher mine, formerly a part of the Lucky Stone group, is in sec. 4, T. 10 N., R. 8 W., about 1¾ miles north of Pine Flat. The property, which was located in 1870, is owned by John D. Grant of Healdsburg. In 1943 the mine had long been idle and the workings were caved, but an old map indicates there were more than 400 feet of workings, consisting chiefly of a single long adit. Poor surface exposures indicate that the workings explored a narrow serpentine mass that is locally silicified, but no ore was seen on the property.

Last Chance and Young Denver Mines

The Last Chance and Young Denver mines, which are just north of the Anne Belcher mine, are owned by Banner Zeke of Healdsburg. Both mines were idle in 1943. At the Last Chance mine, which was located in 1860, about 400 feet of old workings on three levels explored a narrow north-trending silica-carbonate body with a serpentine hanging wall and a sandstone footwall. In places the silica-carbonate rock

contains a little cinnabar. The Young Denver workings consist of about 100 feet of drifts on several levels and some small open cuts. They expose some cinnabar in sheared but unsilicified serpentine.

Denver and Hope Mines

The Denver and Hope mines, which lie north and east of the Last Chance mine, are owned by John Grant of Healdsburg. The Denver was first located in 1861, and the Hope was probably staked at about the same time. Both properties appear to have been abandoned for years, and both were idle in 1944. The Denver mine is said to have produced some quicksilver in the 1860's, but the principal opening, an adit about 1000 feet long, is caved at the portal. No ore was seen on the dumps or in nearby outcrops. The workings of the Hope mine, which consist of an 80-foot shaft and a caved adit of unknown length, explore a small silica-carbonate lens bordering serpentine. This lens is productive at the Socrates mine to the north, but no cinnabar was seen at the Hope mine, either in outcrops or on the dumps.

Boston Group

The Boston group is about a mile east of Pine Flat, on the old road to Pine Mountain. The property is now abandoned and is probably included in the Warner homestead. There is no record of its having yielded any quicksilver, although the mine was known at least as early as 1888. The workings, which were driven to explore a narrow silica-carbonate lens trending nearly north-south, are now caved. They consisted of two adits, one about 75 feet above the other, and short cross-cuts on the ledge. Some ore is said to have been found in the southern crosscut from the lower adit, but no cinnabar was seen in the croppings or on the dump.

Jumbo Mine

The Jumbo property, formerly the Double Star and the B. & M., consists of a group of five claims in sec. 10, T. 10 N., R. 8 W., about two miles east of Pine Flat. The property, which is owned by James G. Cortelyou of Cloverdale, has been idle for several years. Although no production is recorded, the mine probably yielded a small amount of quicksilver. The workings consist of two short adits that explore the southern border of a serpentine body, and several other short adits and shafts. The main workings cut scattered pods of poorly developed silica-carbonate rock containing crusts of cinnabar, some hydrocarbons, and an unusual amount of magnesite. The lack of extensive alteration and the poor showings in the development work suggest that the area is unfavorable for ore bodies.

Cinnabar King Group

The Cinnabar King group, which is about three miles east of Pine Flat, on the west slope of Pine Mountain, is owned by Harold B. Rosenburg of Healdsburg, who reports that the property has yielded a small amount of quicksilver retorted from hand-sorted ore. This is one of several abandoned properties in the vicinity on which prominent lenses of silica-carbonate rock have been explored. No accessible workings other than a few small cuts were found, but early records mention 600 to 800 feet of adits. The silica-carbonate rock is an unusual dense black variety, containing considerable pyrite and small quantities of hydro-

carbons. Cinnabar is sparsely disseminated through this rock in many places, but extensive exploration in the area has failed to reveal any minable ore bodies.

Yellowjacket Mine

The Yellowjacket mine is in sec. 9, T. 9 N., R. 7 W., in Knight's Valley, about two miles south of Mount St. Helena. Information about the early history of the property is vague, but the mine apparently was worked between 1871 and 1875. During that time it attracted considerable interest and probably produced several dozen flasks of quicksilver, but there is no official record of its production.

All the workings are now inaccessible; they consisted of at least two shafts and five adits, whose total length must have been at least a few hundred feet. They explored one of several lenses of silica-carbonate rock exposed in the vicinity, but, as no ore was found on the dumps, nothing was learned about the character of the ore that was mined.

QUICKSILVER DEPOSITS OF EASTERN MAYACMAS DISTRICT LAKE AND NAPA COUNTIES, CALIFORNIA *

By Robert G. Yates ** and Lowell S. Hilpert **
United States Department of the Interior, Geological Survey

OUTLINE OF REPORT

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** Geologist, Geological Survey, U. S. Department of the Interior.

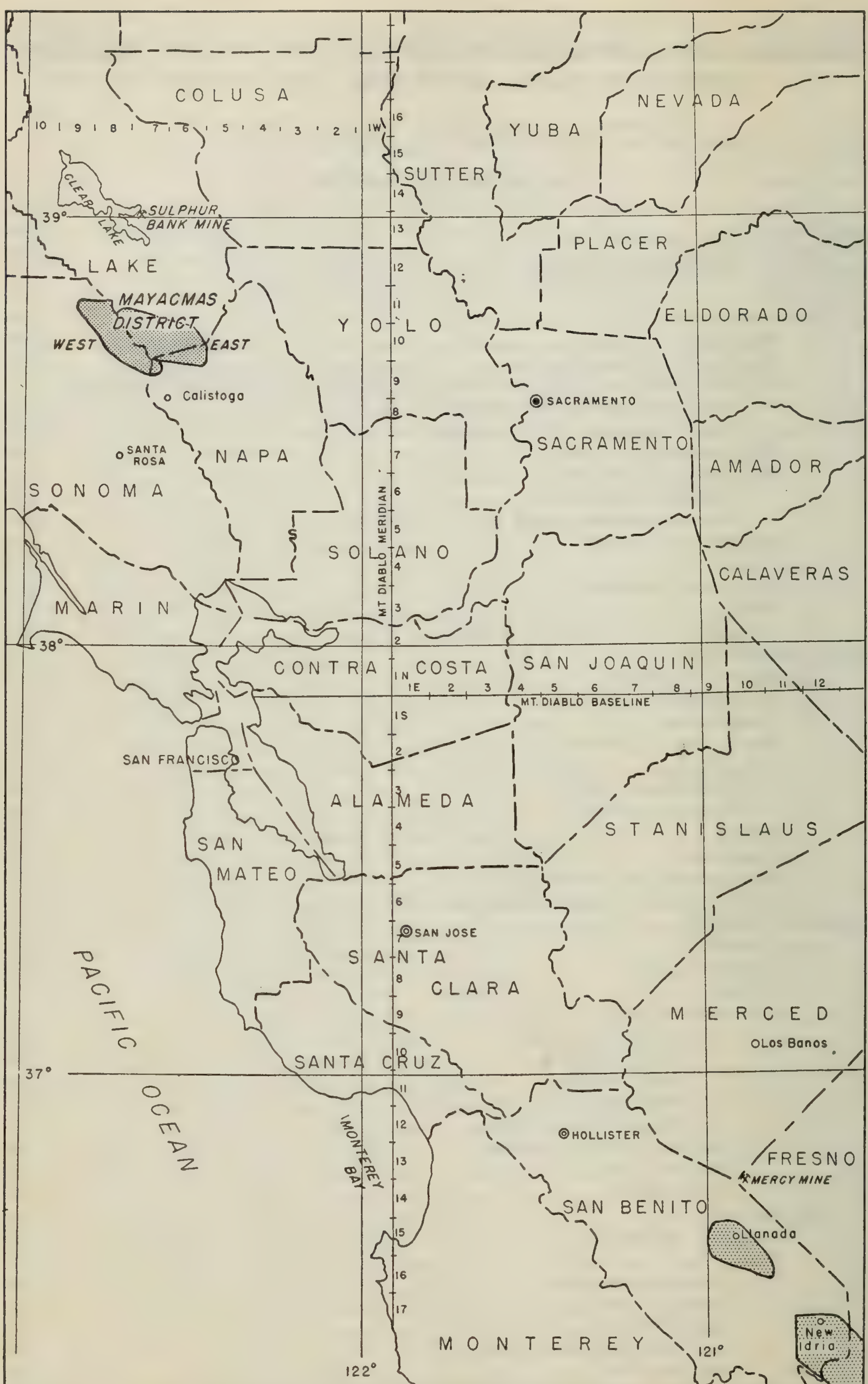

FIG. 1. Index map showing location of Eastern Mayacmas district.

ABSTRACT

The Mayacmas quicksilver district, which includes parts of Lake, Napa, and Sonoma Counties in northern California, has produced over 455,000 flasks of quicksilver since 1864, and is the second most productive quicksilver district in the United States. Only the eastern half of the district, which is credited with 92 percent of the total production, is described in this report. The last quarter of the nineteenth century was the most active period in the history of the district; since then production has declined so sharply that the yield for 1942 was less than 14 percent of what it was in the boom year of 1893. Of the more than 20 mines in the Eastern Mayacmas district, the Oat Hill, Great Western, Aetna, and Mirabel account for over 94 percent of the total production.

The area that includes the quicksilver deposits is underlain mainly by sandstones and shales of the Franciscan group of Jurassic(?) age, but just east of the area of quicksilver mineralization are shales which probably belong to the Knoxville formation, of Jurassic and Lower Cretaceous age. Both the Franciscan and Knoxville rocks are cut by bodies of serpentine, as well as by diabasic and gabbroic rocks. Pliocene and younger lava flows and bedded tuffs cover much of the southern part of the district, and dikes of similar age cut the Franciscan rocks.

Orogenic movements, which passed their maximum intensity before upper Pliocene time, folded and faulted all the rocks. The most prominent structural feature is a broad anticline which trends northwestward through the eastern half of the district. Farther west this anticlinal structure is lost among the heterogeneous attitudes of the Franciscan rocks and is masked by the irregular forms of the serpentine bodies. The quicksilver deposits in the eastern part of the area occur along the flanks of this

anticline, and most of these, as well as those farther west, are along or near contacts between serpentine and sedimentary rocks of the Franciscan group. The rocks associated with the quicksilver deposits are characteristically altered; the sandstones are kaolinized to soft porous rock, and the serpentines are largely replaced by silica and carbonate minerals forming a hard-brittle rock called silica-carbonate rock.

The quicksilver deposits consist of irregular and veinlike rock masses containing disseminated cinnabar, cinnabar-bearing veins, and stockworks of cinnabar veinlets. Metacinnabar and native mercury are found in small amounts in some deposits. Most of the ore shoots have either irregular tabular or pipelike forms. More than half the deposits occur in silica-carbonate rock; the others occur in sandstone and chert of the Franciscan group or within or along the contacts of basalt dikes. All the ore bodies are associated with minor faults, most of which trend northwesterly. The ore shoots are controlled by gouge zones, by changes in dip and strike of faults and contacts, by intersections of shears, and by the degree of premineral brecciation of the country rock. Little is known of the grade of ore which was mined in the early operations, but it was undoubtedly much higher than the average grade of ore (5 to 10 pounds of quicksilver to the ton) mined in 1943.

Reserves of measured ore are negligible, because very little ore is developed in advance of mining. Although the district has passed its zenith, it is still capable of producing 2000 to 4000 flasks of quicksilver per year for several years to come, during periods of high prices. Future production will probably come from relatively unexplored areas adjacent to known mines and from unproved extensions of known ore bodies.

INTRODUCTION

The Mayacmas quicksilver district lies about 70 miles north of San Francisco and includes adjacent parts of Sonoma, Napa, and Lake Counties (see fig. 1). It comprises an area about 25 miles long and 3 to 5 miles wide which extends from Aetna Springs to the vicinity of the Cloverdale mine. The Mayacmas Range, the crest of which makes an arbitrary boundary between the eastern and western halves of the district, crosses the area obliquely. Only the eastern half of the district, which lies in Lake and Napa Counties and is here arbitrarily called the Eastern Mayacmas district, is described in this report; the western half is described elsewhere [1].

Middletown, the only town in the Eastern Mayacmas district, is centrally located at the junction of State Highways Nos. 29 and 53. Calistoga, 17 miles south of Middletown on State Highway No. 29, is the nearest railway shipping point. All the mines are accessible over county and private roads, except for brief intervals during the winter rainy season.

The Mayacmas Range is one of the northern California Coast Ranges. These ranges trend northwesterly and are separated by roughly parallel valleys. The Mayacmas Range consists of moderately rugged mountains from about 2000 feet to over 4000 feet high. The part of the range described in this report is drained by streams that in general flow north and east into Putah Creek, which in turn flows eastward into the Sacramento River. The higher altitudes are heavily wooded, but the lower foothills are either sparsely wooded or densely covered with brush. The flat-bottomed valleys are grass-covered or cultivated. Agriculture is limited mostly to the valleys, where a number of stock ranches, vineyards, and orchards are located. There is a plentiful supply of rough timber for mine use, but sawed lumber is imported.

A preliminary investigation of the Mayacmas district was made in 1938 by C. P. Ross,[2] but at that time many of the mines were inactive

[1] Bailey, E. H., Quicksilver deposits of the Western Mayacmas district, Sonoma County, California: California Jour. Mines and Geology, vol. 42, pp. 199-230, 1946.

[2] Ross, C. P., Quicksilver deposits of the Mayacmas and Sulphur Bank districts, California: U. S. Geol. Survey Bull. 922-L, pp. 327-353, 1940.

and many of the workings were inaccessible. This report is the product of a more extensive examination by geologists of the Federal Geological Survey begun in August 1941 and continued until mid-December of that year. Most of the mines were revisited in 1943, and during May and July 1943 all new and recently opened old workings were mapped. The geology of the district was mapped on aerial photographs obtained from the Agricultural Adjustment Administration. Some of the mine maps were furnished by the operators, and others were made by the field party. Limitations of time necessitated the curtailment of laboratory work and prohibited the solution of geologic problems not directly related to the quicksilver deposits.

The mining men and other residents were courteous and helpful, and gave freely of their time. Information obtained from them has added much to the completeness of this report. The writers are indebted to A. C. Waters and Howel Williams for helpful advice in the preparation of the report.

HISTORY AND PRODUCTION

Cinnabar was first discovered in the Eastern Mayacmas district in the 1850's, but the first recorded production of quicksilver was not until 1864, when the Aetna mine produced 600 flasks. By 1887 all four major mines (Oat Hill, Great Western, Aetna, and Mirabel) were in production, and by 1900 they had passed their zenith and were on the decline. Although more than 20 mines have operated in the district, over 94 percent of the total production came from the above four mines, and two-thirds of the total production came from them between 1875 and 1900. Since the discovery of the Corona mine in 1895, almost a dozen other mines have been opened, but not one of these has contributed materially to the district production. The boom years of the district were 1893, 1894, and 1895, but at the end of this period production dropped rapidly, so that by 1910 the district was no longer outstanding. Production quickened slightly during the first World War, only to almost cease by 1921. Since 1930 there has been a gradual but erratic increase in production, but the district has been unable to respond markedly to the stimulus of increased prices and the emergency of the second World War. Production for 1942 was less than 14 percent of the production for 1893.

Since 1850 California has produced about two and one-half million flasks of quicksilver; the Eastern Mayacmas district has produced about one-sixth of this total, which gives it a rank of second in the United States. Its annual production for recent years, however, has fallen far behind that of several other districts.

Analysis of the data on the accompanying graph (pl. 34) reveals some interesting conclusions. The large mines were discovered early in the history of the district, and although there has been a fairly constant discovery of new mines, none of these has yet proved to be of much importance. This can be seen on plate 34 in the lack of relationship between the number of mines in production and the annual production. Prior to the first World War there was no relationship between price and production; ore bodies were mined as they were discovered, regardless of the current price. Since 1930, however, there has been a very close relationship between price and production, principally because the large high-grade ore bodies were exhausted and mining became more

and more a marginal operation. The high price of 1874 stimulated mining in the district and led to the discovery of the major ore bodies.

GEOLOGY

The area that contains the quicksilver deposits of the Eastern Mayacmas district is underlain mainly by sedimentary rocks of the Franciscan group (Jurassic?) (pl. 29). East of the area of quicksilver mineralization are shales and sandstones which probably belong to the Knoxville formation, of Jurassic and Lower Cretaceous age. Both the Franciscan and probable Knoxville strata are cut by bodies of serpentine, as well as by diabasic and gabbroic rocks. Pliocene and Pleistocene lava flows and bedded tuffs cover much of the southern part of the area, and dikes of a similar age cut the Franciscan rocks. All the rocks are folded and faulted; most of the orogenic movements occurring before upper Pliocene time. The major structural feature is a broad anticline which trends northwesterly through the eastern half of the district. To the west this anticline is lost among the heterogeneous attitudes of the Franciscan sedimentary rocks and masked by the irregular forms of the serpentine bodies. The quicksilver deposits in the eastern part of the area occur along the flanks of this anticline, and most of them, as well as those farther west, are along or near contacts between serpentine and sedimentary rocks of the Franciscan group.

Rock Units

Franciscan Group

The Franciscan group, of probable Jurassic age, is the oldest and the dominant rock unit of the mapped area. It consists largely of sandstone with intercalated beds of shale, but also includes basaltic lava flows, tuffs, and chert lenses. Locally it is metamorphosed to glaucophane schists and other metamorphic rocks. Its measurable thickness exceeds 5000 feet and its total thickness is doubtless several times as much. No fossils were found in it. It is only in fault contact with the younger Knoxville rocks.

The most abundant rock in the Franciscan group is medium-grained gray to greenish-gray sandstone, which ranges from highly indurated to moderately soft, poorly cemented varieties. The weathered rock is buff to brown. Feldspar, quartz, and minor amounts of ferromagnesian minerals are the main constituents. In many places the sandstone is well-bedded and shows little evidence of shearing or crushing; in other exposures, it is highly sheared and contorted and is characterized by numerous quartz and carbonate veinlets. Bedding is emphasized by thin intercalations of black shale, which in some places constitute as much as 25 percent of the whole.

Hydrothermally altered sandstone of the Franciscan group is distinguished on plate 29 by a special symbol. The feldspar grains in this rock are altered to clay and the ferromagnesian minerals are either partly or wholly decomposed. The rock is white to light gray, except where iron-stained. It is soft and crumbles readily wherever exposed to the atmosphere.

Conglomerate is not abundant, except west and north of the Helen mine where a fairly thick bed is exposed. It consists of well-rounded pebbles of quartzite, chert, and porphyry in a sandstone matrix. In size the pebbles range from a quarter of an inch to 6 inches in diameter.

In several small conglomerate lenses the pebbles were flattened and deformed after deposition.

Interbedded with the sandstone are flows of basaltic lava, some basic tuffs, and associated lenses of chert. The lavas are fine-grained and have a dark green color. They are intricately jointed and weather to a rust brown. Pillow structures are common. Elsewhere in California these altered basaltic rocks are termed "greenstones," a name which, although ambiguous, is used hereafter in this report.

Chert lenses are numerous within, and in contact with, the lavas, as well as within the sandstone of the Franciscan group. They range from a few feet to several tens of feet thick and are generally less than 200 feet long. The cherts are well-bedded: individual layers, from half an inch to four inches thick, are separated by thin shale partings. The cherts are commonly reddish-brown, but white, green, and black varieties occur. The beds are commonly wrinkled and, in many places, intricately folded. Davis [3] and other California geologists consider them to be of sedimentary origin; that is, the silica was precipitated on the ocean floor. Although this genesis can not be precluded for the cherts in this area, it is not in agreement with the facts that they are commonly in or near greenstones and that they seem to show gradation to shales in some places. An alternate hypothesis is that the cherts were formed by the selective silicification of tuffaceous and siliceous shales during the extrusion of the basaltic lavas.

In scattered localities in the Franciscan rocks and the serpentine, are blocks of glaucophane schist, some of which are several hundred feet long. Associated with, and closely related to, these blocks are smaller bodies of hornblende, chlorite, and actinolite schist. These metamorphic rocks occur in a few places within the sandstone of the Franciscan group, but more commonly they are along contacts between the sandstone and intrusive serpentine, or are entirely surrounded by serpentine. Glaucophane schist was not found in the shales of the Knoxville formation, nor in the serpentine intrusive into the shales.

Knoxville Formation

The Knoxville formation, of Jurassic and Lower Cretaceous age, consists of gray clay-shale, brown sandstone, a few thin lenses of limestone, and a small amount of conglomerate. Its total thickness in this area is unknown, but is probably several thousand feet. The formation is widely exposed in the eastern part of the area mapped, especially near Aetna Springs (see pl. 29). Several isolated exposures of shale, lithologically similar to the shales near Aetna Springs, occur along Bear Valley Creek, St. Helena Creek, and about one mile west of the Great Western mine. These are also shown on plate 29 as of Knoxville age.

No depositional contact between the Knoxville and the Franciscan rocks was observed. In most, if not in all places, they are separated by intrusive bodies of serpentine, diabase, or gabbro, and where these intrusions are lacking the contact is undoubtedly faulted. In contrast to the Franciscan, the Knoxville rocks are locally fossiliferous, the most common forms being several species of the genus *Aucella* (*Buchia*).

Intrusive Rocks Cutting the Franciscan Group and Knoxville Formation

Serpentine and subordinate but closely associated diabase, gabbro, and diorite of probable late Upper Jurassic age occur as elongate and

[3] Davis, E. F., The radiolarian cherts of the Franciscan group: Univ. California Dept. Geol. Sci. Bull., vol. 11, pp. 235-432, 1918.

irregular bodies within and along the contacts between the Franciscan and Knoxville rocks. The serpentine bodies range from a few feet to two miles wide; one body is over 15 miles long. In the western part of the district, the serpentine occurs within the Franciscan rocks as roughly parallel, sill-like units; in the eastern part of the district, the serpentine occurs largely as emplacements along the contact between the Franciscan and Knoxville rocks, and in the Knoxville rocks. Diabase, gabbro, and diorite were not separately mapped, because any one intrusive body of basic composition usually contains all three in intimate and gradational relationships. Their distribution is closely related to that of the serpentines. Many of these intrusions are too small to show on plate 29, and undoubtedly some were overlooked. The largest basic intrusion is west of Harbin Springs and is roughly outlined on plate 29 as a body about 2 miles long with an average width of over half a mile.

Serpentinized Igneous Rocks. The serpentine of the Mayacmas district originated from ultrabasic igneous rocks (peridotites and pyroxenites) through conversion of the ferromagnesian constituents into serpentine minerals. Relict textures and structures of peridotite and pyroxenite are common. Owing to shearing, however, much of the serpentine retains few of its former characteristics.

The massive, or unsheared variety of serpentine is dark green to blue green where fresh, and rust brown on weathered surfaces. Aphanitic and sugary textures are common; coarsely crystalline textures are rare. Small grains of chromite and magnetite occur as disseminations and podlike segregations. Reticulated veinlets of chrysotile asbestos cut much of the rock. The massive variety is less abundant than the sheared variety and appears to be more common in the serpentine which intrudes the Knoxville sedimentary rocks. Locally it occurs as angular blocks in a matrix of sheared serpentine.

The sheared variety of serpentine is light to pale green where fresh and slightly lighter on weathered surfaces. Its texture is uniformly dense, but in many places a schistose structure has developed through the coalescense of numerous shear planes. Shearing has produced highly polished, slickensided faces, which gleam in the sunlight. Locally the rock is so highly sheared that it is almost impossible to break it except along shear planes. Some bodies of serpentine are composed entirely of the sheared variety; others consist of isolated blocks of massive serpentine embedded in a sheared matrix. Sheared serpentine is universally present along the borders of the massive serpentine, and zones of highly sheared serpentine extend through bodies of relatively unsheared serpentine. The shears are roughly aligned with the elongation of the serpentine masses, but locally they trend in diverse directions. The sheared varieties are apparently no more thoroughly serpentinized than the massive varieties.

All observed contacts between the serpentine bodies and the Franciscan and Knoxville rocks are marked by pronounced shearing of the serpentine, and many of them, by shearing of the sediments also. In places thin lenses of sheared sediments are included in the serpentine; elsewhere tongues of serpentine project into the sediments. Effects on the intruded rocks attributable to magmatic emanations or heat are rare, and none of the effects seen are unquestionably of this origin. At three localities where serpentine intrudes shales of the Knoxville formation,

the shales are indurated for several feet from the contact; but whether this induration was an effect of baking or of silicification was not determined.

The ultramafic rocks from which the serpentine was formed were intruded during at least two periods, or else were intruded intermittently over a moderately long time. The detrital serpentine and the pebbles of sandstone (Franciscan) and shale (Knoxville) bedded in Knoxville rocks indicate that before or early in Knoxville time there was a period of intrusion, orogeny, and erosion. This occurred before the post-detrital serpentine and Knoxville rocks were deposited and intruded by post-Knoxville ultramafic rocks. The presence of this detrital serpentine does not prove that an unconformity exists in this area between the Franciscan and Knoxville rocks but it does prove that the Franciscan strata and strata mapped as Knoxville were not deposited in an uninterrupted sequence.

Although many of the serpentine bodies are elongated parallel to the strike of the enclosing rocks, their dips commonly differ from those of the enclosing beds. Hence most of the bodies are not true sills. It is likely that the Franciscan strata were folded before emplacement of the serpentine and it is apparent that both the Franciscan and Knoxville rocks were folded before the end of emplacement. It is also apparent that the serpentines have been mobilized after their original emplacement as ultramafic igneous rocks; because it is difficult, if not impossible to attribute the shearing in the serpentines to volumetric changes induced through the hydration of the primary ferromagnesian minerals in the process of serpentinization.

Basic Igneous Rocks. Associated with, and intrusive into, the serpentine are basic igneous rocks whose textures and compositions include diabasic, dioritic, and gabbroic varieties. These rocks also intrude the Franciscan and Knoxville strata. The dioritic types appear to be restricted to the serpentine; the gabbroic intrusions are less common than the diabasic and commonly contain diabasic phases.

The diorite occurs within the serpentine as isolated blocks, possibly formed by fracturing of dikes during movement within the enclosing serpentine. It is a light-gray, medium-grained rock, which is resistant to weathering.

The diabasic types are common and grade into the coarser-textured gabbroic types in many places. They are dark-gray to green-gray, medium-grained rocks that weather to red-brown rock of crumbly habit, which does not readily crop out. Where they intrude shale of the Knoxville formation, they have baked it near the contact. An intrusion breccia, composed of blocks and fragments of fine-grained diabase to medium-grained gabbro in an aphanitic ground-mass, crops out as a dike about $1\frac{1}{2}$ miles northeast of Middletown. Small sills of similar material, probably satellites, are exposed in road cuts just west of the dike. The gabbroic types are best developed about two miles north of Oat Hill and immediately southwest of the New Great Western mine. Both of these basic intrusions are associated with serpentine and glaucophane schist. The texture of the rock near the Great Western mine is locally very coarse, individual crystals of pyroxene and plagioclase measuring over 4 inches long. Small dike-like tongues of this coarse gabbro intrude the serpentine.

Silica-carbonate Rock

Associated with the serpentine are tabular and irregular masses composed of silica and carbonate in varying proportions. These rocks were formed through hydrothermal alteration of the serpentine, and are closely associated with most of the quicksilver deposits in the Mayacmas district. Because of this relationship, which is typical throughout the California quicksilver districts, these rocks are commonly known as "quicksilver rocks" or as "ledge rocks." They are called silica-carbonate rocks in this report.

The silica-carbonate rocks shown on plate 29 range from rock composed of almost 100 percent silica to that which contains over 50 percent carbonate. The silica is in the form of chalcedony, opal, and quartz; the carbonate is in the form of dolomite, calcite, and probably ankerite. The silica and carbonate minerals occur in intimate intergrowth and in reticulate veinlets. In the silica-rich varieties the silica in most places is in the form of opal which is rarely white, but commonly ranges from light green to dark green to black. The more carbonate the rock contains the lighter it is in color; gray-whites and light greens are most common. Scattered grains of chromite and magnetite are common in most of the rock. Much of the rock is dense and structureless, but some is composed of reticulate veinlets. Where sheared serpentine was replaced, the rocks have a schistose structure.

In weathered outcrops the silica-carbonate rock is conspicuous; its vivid yellow and rust browns stand out in sharp contrast to the somber grays and greens of the sandstones and serpentines. It forms ridges and knobs that contrast boldly with the smoother, more regular slopes underlain by serpentine. The rock weathers to a lattice of silica veinlets or to a spongy, cellular mass as a result of the leaching of the carbonate minerals.

Except at one locality the silica-carbonate rock shown on plate 35 is associated with serpentine which intrudes the Franciscan rocks. The only place where serpentine that intrudes the Knoxville is altered to silica-carbonate rock is just northwest of the Guenoc reservoir. Almost all the silica-carbonate rock is in the belt of serpentine that extends from Aetna Springs northwestward to, and beyond, the Helen mine. Most of the quicksilver deposits occur along this belt and the silica-carbonate rock is most abundant in the immediate vicinity of the mines. Silica-carbonate rock occurs along both the upper and lower contacts of this serpentine mass, and well within it. Some contacts are gradational, others are sharp. Gradational contacts are more common where massive serpentine was replaced; sharp contacts are more common where sheared serpentine was replaced. Much of the silica-carbonate rock is intimately fractured, and much of it is in fault contact with the adjoining rock. It is doubtful if these fractures and faults indicate more than incipient movements, which continued during formation of the rock and during the quicksilver mineralization.

In an effort to determine the age of the silica-carbonate rock a careful search was made for detrital silica-carbonate rock in the basal tuff beds of the Sonoma volcanics in areas where the tuffs immediately overlie silica-carbonate rock. Abundant sub-angular to angular cobbles and boulders of sandstone (Franciscan) and serpentine were found in the tuffs, but silica-carbonate rocks, which are much more resistant to erosion, are conspicuously absent. Moreover, the silica-carbonate rock tends to

be concentrated beneath the tuffs where they overlap the serpentine. Almost invariably, the silica-carbonate rock in such localities occurs as flat, tabular bodies concordant to the tuff-serpentine contact, and thus in sharp contrast to the steeply inclined and irregular forms of silica-carbonate bodies well within the serpentine masses, and far from any tuff beds.

The conclusion to be drawn from these observations is that even though the age of the silica-carbonate rock can not be definitely determined it is at least in part younger than the Sonoma volcanics, which are of middle or upper Pliocene age. Ross[4] postulated that the silica-carbonate rock is the end-product of the hydrothermal process that converted the ultramafic rocks into serpentine. He attributed the silicification of the tuffs of the Sonoma volcanics that immediately overlie silica-carbonate rock bodies to a second period of silicification. The writers found no evidence to support the assumption that the silica-carbonate rock is closely, or even remotely, related to the process of serpentinization. It is true, nevertheless, that some silicification took place during the Jurassic, because boulders of silicified serpentine were found in a bed of detrital serpentine interstratified with shales and sandstones of the Knoxville formation. These boulders, however, do not resemble any of the silica-carbonate rock mapped on plate 29, and contain no carbonate minerals, being composed entirely of quartz.

Tertiary and Quaternary Volcanic Rocks

Sonoma Volcanics. Large areas of the northern California Coast Ranges are covered with heterogeneous Tertiary and Quaternary volcanic rocks, generally assigned to the middle and upper Pliocene, and Pleistocene. Between San Francisco Bay and the Mayacmas district are volcanic rocks, which have been described by various writers[5], and are here referred to as the Sonoma volcanics. Their age is generally recognized as younger than lower Pliocene, but there is no general agreement as to whether it is middle or upper Pliocene.

In the Mayacmas district the Sonoma volcanics consist of andesitic and rhyolitic tuffs, and flows, flow breccias, and agglomerates of basalt, andesite, and rhyolite. On the map (pl. 29) they are shown as a unit that also includes dikes and plugs which are probably feeders of the flows. In the eastern Mayacmas district the Sonoma volcanics reach their maximum thickness along the southern and southeastern margin, at the crest of the Mayacmas Range, where they are over 2000 feet thick. They are generally flat-lying but locally are inclined as much as 30°. They completely cover the older rocks on the south side of the range, but on the north side most of them have been removed by erosion.

The tuff is predominantly andesitic and ranges from very fine-grained and well-bedded material to coarser pyroclastic rocks that grade into breccia composed of pumice and lava fragments. Some of the blocks in the breccia weigh several tons. A few poorly preserved leaves occur

[4] Ross, C. P., op. cit., pp. 332-333.

[5] Osmont, V. C., A geologic section of the Coast Ranges north of the Bay of San Francisco: California Univ., Dept. Geol. Sci. Bull., vol. 4, no. 3, pp. 59-82, 1904. Dickerson, R. E., Tertiary and Quaternary history of the Petaluma, Pt. Reyes, and Santa Rosa quadrangles: California Acad. Sci., Proc., 4th ser., vol. 2, no. 19, 551, 1922. Morse, R. R., and Bailey, T. L., Geological observations in the Petaluma district, California: Bull. Geol. Soc. America, vol. 46, p. 1454, 1935. Weaver, C. E., personal communication.

in the fine-grained tuffs, but the flora is too meager and poorly preserved for purposes of correlation. The flora, however, indicates a humid climate, which suggests a late Pliocene or early Pleistocene age. In several localities tuffs immediately overlying the Franciscan rocks contain detritus from the Franciscan rocks. Flows of basalt, rhyolite, and andesite occur throughout the tuffs, but they are not nearly as abundant in the area mapped as the pyroclastic material.

Quartz-bearing Basalt Flows and Dikes. Quartz-bearing olivine basalt flows cap the long ridge that separates St. Helena Creek from Long Valley (see pl. 29), and dikes of similar rock intrude the Franciscan rocks near the Aetna mine. Similar flows are about one mile east of the Guenoc reservoir. The basalt is light green-gray where fresh, and dark brown-black on weathered surfaces. Its texture ranges from dense to fine-equigranular. Quartz is present in angular pieces, which range from microscopic size to over one inch long, and appears to be recrystallized foreign material included in the magma during intrusion. The maximum thickness of the basalt is at Oat Hill, where it is about 200 feet. The dikes of olivine basalt are mineralogically identical with the flows and may have been feeders for them. The Silver Bow ore body of the Aetna mine is along the hanging wall contact of one of the dikes. A considerable amount of erosion occurred after the deposition of tuffs of the Sonoma volcanics and before the extrusion of the olivine basalt flows which rest upon erosional remnants of the Sonoma volcanics. The quartz-bearing basalt flows and dikes are therefore of late Pliocene or Pleistocene age. Their relationship to the present topography favors a Pleistocene age and they are therefore classed as Quaternary.

Quaternary Deposits

A large part of the area (pl. 29) is covered by valley fill, talus, and landslide debris. Thin mantles of valley fill of silt, sand, and gravel carpet the floors of the larger valleys. Most, if not all, the talus deposits are partly of landslide origin; they are not differentiated from landslide deposits on the map. Some of the landslide and talus deposits are easily confused with bedrock.

Landslides are widely distributed and range in size from small incipient slides that are too small to show on plate 29, to those over 2 miles long and 1 mile wide. They are characterized by hummocky surfaces and numerous small depressions, in some of which ponds form during the rainy season. Many are composed of a heterogeneous assemblage of blocks in a comminuted shale or serpentine matrix; others are composed of one dominant rock type. Whereas the landslides may include all kinds of rocks, the talus deposits consist solely of blocks of olivine basalt. The talus deposits accumulate on the slopes of ridges capped by olivine basalt flows, and most of them grade downslope into landslides. An interesting landslide-talus deposit is on the southeastern slope of Oat Hill. Here large, tabular blocks of olivine basalt, which are scattered over the hillside, rest in a matrix of clay and soil derived from the disintegration of sandstone of the Franciscan group. The basalt blocks are parts of the lava flow that formerly covered much of this area, but is now only an erosional remnant crowning Oat Hill and the ridge to the north. The blocks were lowered to their present positions by sapping of the weathered and hydrothermally altered sandstone

at the base of the flow and partly by sliding down the oversteepened slope developed below the protective lava cap.

Structure

The sedimentary rocks in the Eastern Mayacmas district are folded, faulted, and intruded by igneous rocks in greatly differing degrees of intensity. The simplest structure is in the eastern half of the district where the Franciscan strata are bowed into an anticline. This structure can not be traced westward through the district, but is lost among the heterogeneous attitudes of the Franciscan strata and masked by the irregular forms of the basic and ultramafic intrusions. The deciphering of the more complex structure of the western half of the district is somewhat handicapped by the paucity of good exposures and lack of definite stratigraphic units, but more so by the irregular nature of the serpentine intrusions.

The structure of the serpentine masses has so influenced the general structure of the area that these rocks are discussed separately in a section below. The large, irregular serpentine masses in the Eastern Mayacmas district are in contrast to the narrow sinuous serpentine bodies in the Western Mayacmas district,[6] which are controlled by broad shear zones. These shear zones are not apparent in the Eastern Mayacmas district, but may be engulfed by some of the larger serpentine masses.

Mayacmas Anticline

The major structure of the district is a broad, open anticline, which trends from Aetna Springs northwesterly as far as the valley of St. Helena Creek. On the west side of the valley this anticline is no longer discernible and apparently does not exist as a simple anticlinal structure. The core of the anticline is composed of Franciscan rocks; its flanks are formed by shale of the Knoxville formation and serpentine. In the vicinity of Aetna Springs the anticline plunges to the east; it does not project into Pope Valley. Structural relationships at the nose are complicated by faulting.

Plate 29 shows the general form of the Mayacmas anticline; but because of the lack of subdivisions in the Franciscan rocks, it fails to show the internal distortion. The Franciscan rocks in the core have erratic dips and strikes, because of the numerous small folds and faults, which do not show on the map. Although these minor structures are not persistent, they give the impression that the anticline is much more complex than it probably is. Many of them probably were produced during the folding of the anticline.

Faults

All the rocks are faulted, but there are no large through-trending faults which cross the district. The largest fault mapped, just northeast of Oat Hill (see pl. 29), was traced for two miles and possibly extends twice that distance. It probably connects with the fault that cuts off the nose of the Mayacmas anticline. These two faults, together with the northeast-trending fault at the Aetna mine, thus seem to rim the nose of the anticline. The serpentine bodies are bounded in places by post-intrusion faults, but as these are difficult to distinguish from intrusive contacts they are discussed below in a separate section. The Franciscan

[6] Bailey, E. H., op. cit.

rocks, and, to a lesser extent the Knoxville rocks, are cut by numerous faults and shear zones which, because of their lack of continuity, are not shown on plate 29. The volcanic rocks of Pliocene and Quaternary age, although generally undisturbed, are locally broken by faults.

The faults, most of which trend northwest, are both normal and reverse, the reverse faults including both thrust and strike-slip varieties. The ore-bearing faults at the Oat Hill mine are normal; that at the Corona mine is a thrust; and some of those at the Aetna and Great Western mines are strike-slip faults. Horizontal striae on slickensides on many fault planes indicate that the last movements were, at least in part, of a strike-slip character. Dips of the fault planes range from 30° to vertical and they apparently tend to steepen in depth. Along their strikes the faults tend to die out by splitting or by passing into the bedding.

Much of the fault movement in the Franciscan rocks was not restricted to isolated fault planes but was distributed through breccia and shear zones, which, although locally over 100 feet wide, tend to pinch and disappear within short distances along the strike, indicating that the intense brecciation does not represent major movements. The fault zones are composed of lenticular to angular blocks and fragments of sandstone, chert, and greenstone in a finely pulverized shale matrix. They rarely crop out, except in stream and road cuts, but can be well observed in some of the mine workings. Underground the breccia zones usually exhibit a well-developed lineation, made apparent by the breccia blocks and subparallel arrangement of shears. These breccia zones commonly contain more shale than the unbrecciated Franciscan rocks; therefore, their distribution is probably controlled by the inherently weak, more shaly phases of the Franciscan rocks.

Many of the faults probably originated as direct results of the intrusion of the basic and ultramafic rocks and many probably originated during the regional folding of the Knoxville rocks. A few faults are later than the Pliocene Sonoma volcanics and a few cut the quartz-bearing Quaternary lavas. Some of these late faults probably are rejuvenations of much older faults. It is these late movements, and in particular those which rejuvenated old faults, that are directly related to the quicksilver deposits.

Structure of the Serpentine Bodies

The peripheries of all the serpentine bodies are sheared, and in many places the shearing and accompanying brecciation extend into the intruded Franciscan and Knoxville rocks. Zones of sheared serpentine also extend across the serpentine bodies. The peripheral shearing and brecciation may be either an intrusion or a post-intrusion structure or, as it is in many places, a combination of both. The shear zones which extend across the serpentine bodies are related to forces operating after the emplacement of the serpentine bodies.

The sheared serpentine is described in another section of this report. The zones of brecciated Franciscan rock, which in many places rim the serpentine bodies, greatly resemble the fault breccia previously described. Brecciated Franciscan rocks are most common where the intrusions cut across the bedding of the sediments and are least common where the intrusions are true sills. Sheared serpentine is locally separated from brecciated Franciscan rocks by black, plastic, clay-gouge, commonly

referred to as ''black alta'', which forms the hanging wall of many ore bodies. Wedges and slivers of black alta commonly occur as inclusions in the serpentine near the borders of the intrusions.

The lack of any relationship between degree of serpentinization and intensity of shearing precludes the possibility that the shears within the serpentine bodies were formed by increase in volume of the intrusive masses during their conversion to serpentine. From a careful study of the areal map (pl. 29) it is evident that all the serpentine bodies can not be faulted into their present positions; it is equally evident that all of them can not occupy pre-intrusion fault zones. Part of the brecciation and shearing along the borders must therefore have been produced by the mechanics of intrusion. In addition, part of the brecciation must be a post-intrusion phenomenon; as for example, breccia in the Great Western mine, which contains angular blocks of serpentine in crushed and sheared sandstone and shale.

The serpentine bodies are believed to have been emplaced essentially in their present positions as peridotites and pyroxenites, which were contemporaneously converted to serpentine by the action of the volatile components of the ultramafic magma. The first intrusions may have been sills between folded beds, but as igneous activity progressed the strata became more and more deformed, so that there was increasing tendency for the intrusions to cut across the bedding As they did so, they faulted and brecciated the strata, and in some places actually faulted their way into the sediments. The serpentines, being soft, weak rocks that readily yield to compressive stresses, were repeatedly sheared during the numerous movements which took place in the California Coast Ranges during Cretaceous and Tertiary time.

ORE DEPOSITS

Quicksilver Deposits

The quicksilver deposits of the Eastern Mayacmas district consist of irregular and veinlike rock masses containing either disseminated cinnabar, cinnabar-bearing veins, or stockworks of cinnabar veinlets. Native mercury and metacinnabar are accessory ore minerals in some of the mines. Most ore shoots, though of irregular form, are roughly tabular or pipelike. More than half the deposits occur in silica-carbonate rock; the others occur in sandstone of the Franciscan group, in chert, or along and near the contacts of basalt dikes. All the ore bodies are associated with minor faults, which commonly trend northwesterly. The ore shoots are controlled by local gouge zones, by changes in dip and strike, by intersection of shears, and by the degree of pre-mineral brecciation of the country rock. Little is known of the grade of ore mined by the early operators, but undoubtedly it was higher than the 4 to 15 pound (quicksilver to the ton of ore) ore mined in 1942. Very little ore is developed in advance of mining; consequently reserves can not be measured. Although the district is definitely on the downgrade, it will continue to produce quicksilver for some years to come.

Mineralogy

The accompanying table lists all the minerals known to be genetically associated with the quicksilver deposits. Rock-forming minerals having no more than a spatial relationship to the ore deposits are not included.

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Table 1. Minerals genetically related to the quicksilver deposits of the Eastern Mayacmas district

	Name*	Composition	Remarks
Mercury minerals	CINNABAR	HgS; red mercuric sulphide	Most important ore mineral in all mines described.
	Native mercury	Hg	Small globules in vugs and fractures in most silica-carbonate rock ore. Not commercially important.
	Metacinnabar	HgS; black mercuric sulphide	Known at Mirabel and Great Western mines; reported at Aetna and Helen mines.
	Tiemannite	HgSe; mercuric selenide	Reported at Helen mine.
Sulphide minerals	PYRITE	FeS_2; ferric sulphide	Widespread and locally abundant in all ores.
	Marcasite	FeS_2; ferric sulphide	Abundant in Helen, Corona, and Twin Peaks ores.
	Millerite	NiS; nickel sulphide	Reported in Aetna, Twin Peaks, and Great Western mines.
Silica minerals	CHALCEDONY	SiO_2; silica	Most abundant silica mineral in silica-carbonate rock. Ores of Great Western, Aetna, and Mirabel.
	OPAL	$SiO_2 . nH_2O$; hydrous silica	Most abundant silica mineral in silica-carbonate rock ores of Corona, Twin Peaks, and Helen mines.
	Quartz	SiO_2; silica	Commonly occurs as late veins in silica-carbonate rock.
Carbonate minerals	DOLOMITE	$CaCO_3 . MgCO_3$; calcium magnesium carbonate	Most abundant carbonate in silica-carbonate rock; forms late veins in Mirabel and Great Western mines.
	Calcite	$CaCO_3$; calcium carbonate	Occurs as late veins and fills vugs in silica-carbonate rock.
	Ankerite	Calcium, magnesium, iron carbonate	Probably common in some silica-carbonate rock.
	Magnesite	$MgCO_3$; magnesium carbonate	Uncommon as concretionary masses and veins in silica-carbonate rock.

Clay minerals	*Saponite*	Hydrous magnesium, aluminum, silicate	As pods and veins in serpentine and silica-carbonate rock in Twin Peaks mine.
	Clays	Undetermined	Undetermined clays widespread as alteration products of rock minerals.
Hydro-carbons	*Napalite*	C_3H_4; simple hydrocarbon	Reported in Aetna mine.
	Curtisite	$C_{24}H_{18}$; simple hydrocarbon	Occurs in Helen, Research, and probably other mines.
	Posephyte	Oxygenated hydrocarbon	Reported in Great Western mine.
	Oils and tars	Complex hydrocarbons	Common in silica-carbonate rock ores.
Secondary minerals	LIMONITE	Hydrous ferric oxide	Common as an alteration product of pyrite and marcasite.
	Opal	SiO_2nH_2O; hydrous silica	Forms crusts and stalactites on silica-carbonate rock.
	Quartz	SiO_2; silica	Lines vugs and fractures.
	Gypsum	$CaSO_4 . 2H_2O$; calcium sulphate	Formed through action of sulphate waters (produced by oxidation of iron sulphides) on various minerals; occur as crusts and stalactites on mine walls and timbers.
	Epsomite	$MgSO_4 . 7H_2O$;	
	MELANTERITE	$FeSO_4 . 7H_2O$;	
	Copiapite	$Fe_4(OH)_2(SO_4)_5 . 18H_2O$	

* Capitals denote mineral is abundant or widespread, or both; lower case denotes mineral is moderately widespread; italics denote mineral is rare.

More detailed microscopic studies would doubtless reveal other minerals, but these would be of no quantitative importance.

Cinnabar, by far the most important ore mineral, occurs as granular and massive fillings, as incrustations in vugs and fractures, as irregular masses and lenses, and as disseminated crystals. It was deposited mostly in open spaces, but some was formed by the replacement of other minerals. Some cinnabar is a bright red, pulverulent powder which coats fracture faces and fills small vugs. This cinnabar may be secondary in origin; that is, formed through ground-water action on primary cinnabar. Native mercury was observed only in silica-carbonate rock gangue, where it fills small vugs and open fractures. Metacinnabar, the black sulphide of mercury, was locally important in the Great Western and Mirabel mines as an ore mineral. It is associated with cinnabar and occurs in a similar manner. In general, the iron sulphide minerals, pyrite and marcasite, commonly associated with cinnabar, appear to be of an earlier origin, although in some specimens the pyrite appears to be contemporaneous with, or possibly later than the cinnabar.

The silica and carbonate minerals that compose the silica-carbonate rock are the most important gangue minerals. Although there is a great amount of overlapping, the silica minerals are, in general, older than the carbonate minerals. There is no relationship between ore and the ratio of silica to carbonate.

Clay minerals, formed at various stages of the mineralization, and hydrocarbon compounds, formed at a late stage, are associated with many of its quicksilver deposits. The clays are most common in deposits in sandstone or are associated with basalt dikes. Saponite, a magnesium clay, occurs as an alteration of serpentine at the Twin Peaks mine. Other clays, of undetermined composition, are common to the deposits in sandstones. Hydrocarbon compounds were observed only in silica-carbonate rock, and only in that which contained either cinnabar or pyrite. They occur as definite crystals and as tars and oils which fill small fractures and vugs. In the Helen mine, small, spheroidal shells of cemented quartz crystals are filled with a light oil. Wherever the age relationship between hydrocarbons and cinnabar could be observed, the hydrocarbons were later.

Distribution

The distribution of the quicksilver deposits of the Eastern Mayacmas district is shown on plate 29. A few prospects outside the mapped area are briefly discussed under the descriptions of individual mines. Most of the deposits are within a belt less than 1 mile wide which trends N. 65° W. from Aetna Springs, to the summit of the Mayacmas Range. In the eastern two-thirds of the district, this restricted quicksilver belt closely parallels the northeastern boundary of a large serpentine mass, and most of the mines are along or close to the contact of the serpentine with the intruded Franciscan rocks. A few of the mines in this part of the district, notably the Oat Hill and Toyon, are a little outside this narrow belt and have no apparent relationship to the contact between the serpentine and Franciscan rocks. In the western third of the district the quicksilver belt crosses the serpentine mass, and most of the mines are along the southwestern contact of the serpentine with the Franciscan rocks, or are within the serpentine mass. Four mines in the extreme western part of the district are outside the restricted quicksilver belt and have no apparent structural relationship to the other deposits.

All the quicksilver deposits in the area mapped are in the Franciscan group or in serpentines or basalts intrusive into the Franciscan group. Although no deposits are along large faults, all are along minor faults or along or near intrusive contacts which have been subjected to post-intrusion movement.

Form and Character

The quicksilver deposits of the Eastern Mayacmas district are separable by their host, or gangue, rock into four different types of ore bodies. These are: (1) ore bodies in silica-carbonate rock, exemplified by the Corona mine, (2) ore bodies along faults in sandstone of the Franciscan group, exemplified by the Oat Hill mine, (3) ore bodies in or along the contacts of basalt dikes, exemplified by the Silver Bow ore body of the Aetna mine, and (4) ore bodies in brecciated chert, exemplified by ore bodies in the Old Great Western mine.

Ore bodies in silica-carbonate rock are the most abundant and include some of the richest and largest ore shoots. They are either tabular or pipe-like and may have either a hanging or foot wall of Franciscan rocks, from which they are commonly separated by a layer of gouge. Some silica-carbonate rock ore bodies are located well within the serpentine masses; these are notoriously the poorer deposits of this type. Cinnabar occurs in well-defined veins, in small veinlets that form stockworks, and as crystals disseminated in the silica-carbonate rock. The walls of the ore bodies are sharp where bounded by faults or shears or gradational where the cinnabar is disseminated.

Ore bodies along faults in sandstone of the Franciscan group are not numerous, but the most productive mine in the district, the Oat Hill, consisted of ore bodies of this type. These ore bodies are tabular or vein-like and are formed either parallel to the faults with which they are associated, or to the bedding adjacent to the faults. Cinnabar fills small fracture openings along the faults and spaces between sandstone grains along and for some distance away from the faults. These ore bodies are commonly bounded by assay walls.

Ore bodies associated with basalt dikes are rare and have been mined only in the Aetna and Helen mines. The best known and most productive is the Silver Bow ore body of the Aetna mine. These ore bodies are tabular or veinlike and occur along the hanging wall contacts of the dikes. Cinnabar, associated with pyrite, occurs in the altered basalt and brecciated sandstone and shale along the hanging wall contacts, and also in the interior of the dikes, as incrustations along joint planes. The walls of these ore bodies are normally sharp, but in a few places they are poorly defined.

Important production came from ore bodies in brecciated chert in the Old Great Western mine during its early history, but as the stopes are now inaccessible, descriptions of this type of ore body must be based largely upon the accessible, but much smaller and less important Pope ore bodies of the Aetna mine. These correspond in size and shape to the chert lenses that enclose them; they are roughly lenticular and pinch out within short distances along both the strike and dip. Cinnabar occurs as fillings between chert fragments and along shale partings in the chert. In general, the best ore is in the most highly brecciated chert.

All four types of ore bodies share an association with faults or closely jointed or highly brecciated rocks. There is some overlapping

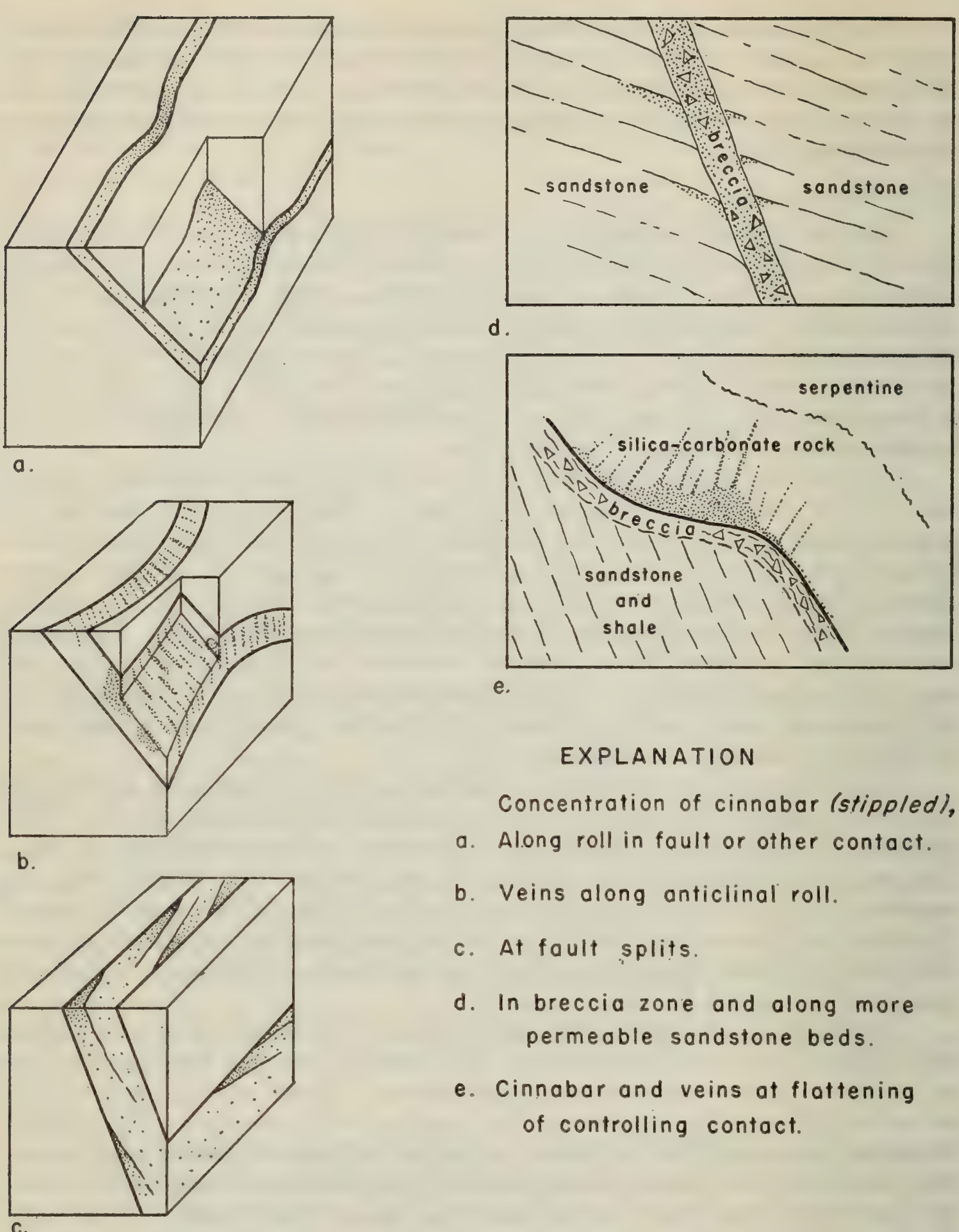

Fig. 2. Diagrammatic sketches of structures which controlled ore in Eastern Mayacmas district, California.

of types; for example, the Star vein of the Aetna mine is along a fault in Franciscan sandstone, as well as along a basalt dike.

Ore Shoots

Structural Control. Minor structures control the distribution of the ore shoots, just as major structures control the distribution of the mines. Structural factors that localized ore shoots are complex, and unfortunately the control is not always determinable before the ore body is nearly exhausted. In many places, however, the controlling struc-

tures can be identified early in the mining of the ore body, and the knowledge thus gained can be used in later development. The early recognition of the structural control of ore shoots is therefore important.

In all the ore bodies there are barren spots and places too low-grade to mine; conversely, there are places where structural conditions favored the formation of ore shoots. These conditions were most commonly satisfied in the Eastern Mayacmas district along faults and intrusive contacts, and most of the ore bodies were formed in the open spaces associated with such features. Although cinnabar locally makes room for itself by replacing previously formed minerals, it is commonly deposited in open spaces; therefore, porous, jointed, or brecciated rocks are most favorable to the accumulation of an ore body. Interconnected rock openings act, in the aggregate, as both channelways for ore solutions and reservoirs for ore bodies, a channelway being a passage along which the ore solutions travel from a deep-seated source to the surface, where they mingle with ground and surface waters. If the physical and chemical environments along the channelways were constant from the source of the solutions to the surface the mercury in solution would not be deposited in the channelway but would be carried away by surface waters and no ore bodies would be formed. Ore bodies were formed, however, and relatively near the surface. This indicates that the environment through which the solutions passed did change, and changed most radically near the surface. The physical and chemical factors which must have been involved in these changes in environment are not clearly understood and cannot be discussed here. There are, however, certain structural features whose constant association with quicksilver ore bodies suggests that they controlled local changes in environment, and hence converted channelways into ore reservoirs.

Observed structural variations that controlled the localization of ore shoots in the channelways are relatively impervious barriers, changes in strike and dip of the channelways, and relative volumes of rock openings. The channelways may be fault, shear, or crush zones, and they may be identified as channelways by traces of cinnabar or by the presence of gangue minerals associated with the cinnabar mineralization.

Barriers of impervious rock sharply limited the number of channelways and thus caused great volumes of ore solution to pass through a restricted volume of rock. The most common barrier is gouge, or black alta, but shale layers in sandstone play an important role. The barrier need only be impermeable relative to the adjacent rocks. It does not trap the solutions but guides them along definite courses in their upward journey.

Ore shoots as well as the tenor of the ore in many places show a direct relationship to variations in strike and dip of the channelways. Where the strike curves to form a "roll", the ore may be richer along the axis of the roll. Where the dip flattens the ore likewise may become richer. This, however, is not universally true.

Shears and joints locally control ore shoots by providing abundant open spaces for deposition of cinnabar. Parallel, closely spaced shears, surrounded by relatively unbroken rock, are particularly favorable. Points of intersection and division of faults are favorable, because the maximum amount of open space is most apt to occur there.

Several structural controls of ore shoots are diagrammatically illustrated by figure 2.

Size and Grade. In size the ore shoots range from a few feet to several hundred feet in drift length and stope depth, and from a few inches to 100 feet in width. The largest stopes were mined in the Great Western mine, where at the time of Becker's[7] visit, shoots 500 feet high, 150 feet long, and over 50 feet wide were extracted. The deepest ore shoot was on the Manzanita vein of the Oat Hill mine, which was mined to a depth of 750 feet and probably averaged 10 to 20 feet in width. The length of this vein is unknown, but it was probably several hundred feet. Some of the ore shoots in the Mirabel and Aetna mines closely approach in size those in the Great Western and Oat Hill mines. In these large shoots the best grade of ore was commonly in the central part of the shoot, but in some places high-grade ore extended to the surface. As no records were kept, only a general approximation of the grade of ore mined in the early days can be made. Prior to 1900 the average tenor of ore must have exceeded 10 pounds of quicksilver to the ton, and may have been twice that figure. Ore treated in the furnaces during 1942 averaged between 2 to 10 pounds of quicksilver to the ton.

Origin

The quicksilver deposits of the Eastern Mayacmas district, which were formed by ascending hot solutions, are associated with fault and intrusion breccias. As previously mentioned many of these structural features originated during the latter half of Jurassic time, when the first intrusions of ultramafic magma began. Little is known of the detailed structural history of the area from the opening of Cretaceous time until the deposition of the Sonoma volcanics in Pliocene time, but as the little-disturbed Sonoma rocks overlap the eroded edges of folded and faulted Franciscan rocks, there must have been extensive orogenic movements during this interval. Before Sonoma time the Mayacmas Range was as high, if not higher than at present. After Sonoma time, minor fault movements, relatively quiet volcanism, and erosion ensued. It was these late structural movements that paved the way for the quicksilver mineralization.

Probably during the Pliocene or Pleistocene faulting, solutions ascended along faults and intrusive contacts and replaced the adjacent serpentine by silica and carbonate minerals and altered the feldspars of the sandstone to clay minerals. Contemporaneous and succeeding movements fractured the newly formed silica-carbonate rock and reopened closing channelways in the sandstone, thereby providing openings for the ore-bearing solutions. These rising solutions carried iron, mercury, sulphur and other elements, which they deposited as cinnabar, pyrite, and other minerals in the newly formed fractures and pore spaces. Deposition of cinnabar was caused mainly by cooling of the solutions on approach to the surface, but the structural factors discussed above influenced the concentration of cinnabar in ore shoots.

Lack of extensive erosion since the formation of the deposits confirms the opinion that they were formed under conditions of relatively low temperature and pressure and are, thus, of epithermal origin. The irregularity of the ore shoots, the abundance of pre-mineral fractures, and the absence of high-temperature minerals all add further support to this contention. All the above also confirm a late age for the quicksilver mineralization.

[7] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, pp. 360-361, figs. 15 and 16, 1888. (Also see plate 41*A* in this report.)

Although the mineralization was younger than the Sonoma volcanics, no minable ore has yet been found in these rocks. Possibly commercial deposits of quicksilver occur in these rocks, or were formerly present and have since been eroded.

Reserves

Even an approximate estimate of the quicksilver reserves is a difficult, perhaps impossible, task because of the irregular nature of the deposits, lack of exploration or development in advance of mining, and the scarcity of information on the old, inaccessible workings. The irregularity of the deposits and their common tendency to end abruptly or pick up without forewarning is the greatest difficulty. The common mining practice of "following the ore," without any knowledge of its extent beyond the working face, does not block out ore reserves. If the old workings were more accessible—and in some cases, if there were even maps of the old workings—much more could be said about the extent of possibly mineralized ground. Reserves of blocked out or measured ore are negligible, and reserves of indicated ore are almost negligible.

On the basis of the geologic character and the past production of the district, it seems reasonable to infer that the district will continue to produce at a rate of from 2,000 to 4,000 flasks per year for several years to come—if a price level of $175 per flask is maintained. This, however, will necessitate increased exploratory work, because much of the ore now being treated comes from stope fill, pillars, and old stope borders. In some of the mines there is a considerable, but unmeasured, amount of stope fill that can be profitably extracted.

Suggestions for Prospecting

The Eastern Mayacmas district has been extensively prospected, but as much of the prospecting was superficial and little of it systematic, possibilities for the discovery of new ore bodies are by no means exhausted. As an aid to future prospecting certain favorable areas may be delimited. On the geologic map of the district (pl. 29) areas of rock alteration associated with quicksilver mineralization are designated by a distinctive map pattern. This altered rock is silica-carbonate rock and kaolinized sandstone, either of which may contain cinnabar, although altered rock is in itself no proof of the occurrence of cinnabar.

In prospecting areas of altered rock, particular attention should be paid to those localities where the rocks are brecciated, fractured, and faulted. Abundant veinlets of quartz, dolomite, or calcite denote favorable ground. Hydrothermally altered sandstone should not be confused with sandstone altered by weathering.

More specific suggestions for prospecting in and about the mines are given under the descriptions of the individual properties. The irregular nature of the structures that control the ore shoots prohibits their projection for more than short distances beyond the working faces; consequently, more extensive exploratory drilling within and close to areas of mineralized ground is recommended.

Chromite, Manganese, and Copper Deposits

Several small deposits of chromite, manganese, and copper occur within the mapped area, but, because of their relative unimportance, they were only superficially examined.

Chromite occurs as small pods and disseminated grains in bands in serpentinized dunite (peridotite). The three most important prospects are at the Great Western mine, on the summit of the Mayacmas Range about 1¼ miles southwest of the Great Western mine, and about ½-mile south of the Mirabel mine. (For more exact locations see plate 29.) Some ore was shipped from the Great Western deposit during the first World War.

A lens of manganese oxide, closely associated with chert and greenstone of the Franciscan group, occurs on Dry Creek about 3 miles southwest of Middletown. This undeveloped manganese prospect is the only one in the Eastern Mayacmas district known to the writers.

One copper prospect is in Napa County, just south of the Lake County boundary on the west side of St. Helena Creek; another is in Lake County, about 1 mile west of Harbin Springs. Native copper and copper carbonates are reported to occur in serpentine in the St. Helena Creek prospect and copper carbonates occur in gabbro in the Harbin Springs prospect. As far as is known, no ore has been shipped from either of these prospects.

MINING AREAS

To facilitate description, the quicksilver deposits of the district are divided into seven groups. Six groups are geographic and are within the map area; miscellaneous prospects outside the map area form the seventh group. If a deposit has a recorded production of quicksilver, it is referred to as a mine; if not, as a prospect. In the descriptions that follow, the mining areas are considered in order from east to west, and the mines within each area are arranged in alphabetical order.

Aetna Area

General Geology

The Aetna area, which is in Napa County at the extreme eastern end of the mapped area (pl. 29), includes the Aetna, Aetna Extension, Ivanhoe, and Valley mines. The country rocks are sandstone (Franciscan), shale (Knoxville), serpentine, silica-carbonate rock, volcanic tuffs (Sonoma) and intrusive olivine basalt. Structurally, the area is on the south flank of the nose of the Mayacmas anticline. The serpentine separates the Franciscan rocks from the Knoxville rocks; it is in intrusive contact with the Franciscan rocks and in fault contact with the Knoxville rocks. The Knoxville-serpentine fault contact trends in a northeast direction and joins the fault that cuts the nose of the anticline. The Franciscan-serpentine intrusive contact dips south in general, but at Red Hill it is horizontal. The serpentine in the Aetna area and that north of James Creek are probably parts of a sill-like body that extended across the nose of the anticline before the latter was breached by the erosion of James Creek canyon.

The Silver Bow dike, the only large olivine basalt dike in the area, trends N. 15° E. and dips about 45° east. It pinches and flattens at its north end and terminates bluntly at its south end. Hanging and foot walls of the dike are altered to white clay, the zone of alteration being thicker along the hanging wall. Breccia and black clay gouge separate unbroken Franciscan rocks from the dike.

Much of the serpentine within the mineralized area is altered to silica-carbonate rock. Boundaries between unaltered serpentine and silica-carbonate rock are either sharp or gradational; most of the sharp ones are fault contacts and many of them controlled the ore deposition.

Faults are abundant in the Aetna area, but none of them extends outside the area and probably none has any considerable displacement. Only the larger faults are shown on plate 29, but maps of the underground workings show others which are too small to show on the surface map or could not be detected because of alluvial cover.

All four types of ore bodies are represented in the Aetna area; in fact, all four occur in the Aetna mine. Many of the known ore bodies are depleted, but there are good opportunities of discovering extensions of these bodies or new bodies through intensive exploration.

Mines

Aetna Mine

The Aetna mine (formerly Aetna Consolidated, Pope Valley), in secs. 2, 3, T. 9 N., R. 6 W., is the third largest mine in the Mayacmas district, and is about a mile west of Aetna Springs. It is directly connected by county roads with both Middletown and Pope Valley. In 1943 the lease and option to purchase were held by the Basin Montana Tunnel Company, of New York City, under the management of A. A. Ryan Jr. The property comprises five patented claims: (1) Phoenix, (2) Silver Bow, (3) Star, (4) Pope, and (5) Red Hill. Cinnabar was discovered in the Eastern Mayacmas district on the Phoenix claim in 1854, but since then ore bodies have been mined from the Silver Bow, Star, and Pope claims. Boundaries of these claims are not shown on plate 35, but the mine workings bear the name of the claim on which they are located. One fairly large open pit is on the property, but the mine is developed chiefly by horizontal adits and inclined raises. Less than half of the mine workings were accessible during the examination; consequently, descriptions of parts of the mine are based upon old maps and published records. Total production for the Aetna mine is over 66,000 flasks of quicksilver, but an accurate estimate is not possible, for, during several years when the Napa Consolidated Quicksilver Company operated both the Aetna and Oat Hill mines, production figures for both properties were combined.

The various parts of the Aetna mine are geologically distinctive, and are, therefore, described separately below.

Phoenix Workings. The Phoenix workings consist of three levels (the No. 7, No. 7½, and No. 8 tunnels) and an open cut and accompanying glory holes. The portal of No. 8, the lowest tunnel, is 138 feet below the portal of No. 7 tunnel, which in turn is about 50 feet below the original outcrop of the ore body. The glory holes are connected with the No. 7 tunnel. In December 1941, the only accessible tunnel was No. 7, and it was caved about 400 feet from the portal. In May 1943, the No. 8 tunnel was open, but the No. 7½ tunnel still was caved at the portal. Most of the ore taken from the Phoenix workings was mined during their early history; since then mining in this area has consisted of robbing pillars and removing low-grade ore left by the early operations.

The country rocks of the Phoenix workings are dominantly serpentine, but there are minor amounts of sandstone and shale (Franciscan), principally near the portal of the No. 8 tunnel (see pl. 36) and also as slivers and wedges of breccia and black alta throughout the serpentine. Most of the serpentine on the upper level, and much of it on the lower level, is altered to silica-carbonate rock. Except where faulted, contacts between the serpentine and silica-carbonate rock are gradational.

The ore is in the silica-carbonate rock, in three nearly parallel, northwesterly, vein-like zones termed the Phoenix, Toothache, and Red Hill veins. These "veins" strike N. 25° W., N. 25° W., and N. 50° W., respectively, and are vertical or dip steeply southwest. They were formed along shears whose last movement was strike-slip, as evidenced by mullion structures and striations on slickensides. On the No. 7 level the shears are multiple and the better ore appears to have been within acute angles formed by intersections of these shears. On the No. 8 level the veins lie along single shears, and the ore is spotty, occurring as irregular low-grade chimneys. The Phoenix vein, the largest and richest vein, was stoped principally above the No. 7 level, and all the open-pit and glory-hole work was done along it. There is little cinnabar on the vein on the No. 8 level. The Toothache vein was stoped only on the No. 7 level and the Red Hill vein was stoped only on the No. 7½ level.

Cinnabar is the only ore mineral; it occurs as fracture fillings and to a lesser extent as disseminated crystals in the silica-carbonate rock. In the upper parts of the Phoenix vein it probably composed 1 percent or more of the rock. On the No. 8 level the cinnabar is mostly the soft, pulverulent, bright red variety, and the ore appears to be of much higher tenor than it actually is.

The Phoenix ore bodies of the Aetna mine appear to be almost exhausted; it is possible, however, that new ore bodies can be discovered. Other small veins may exist between the Toothache and Red Hill veins; but as this ground has been partly explored by the now inaccessible No. 7½ tunnel, it warrants little attention until this tunnel is reopened. Geologically, the most favorable prospecting ground is at the intersection of the Phoenix and Toothache shears with the contact of the serpentine and the underlying Franciscan sandstone. The serpentine about these intersections is probably altered to silica-carbonate rock, which may be mineralized with cinnabar. The shears may cross the serpentine contact and extend into the underlying sandstone, where they may be ore-bearing fractures similar to those in the Star workings. If the shears do not cross the contact of the serpentine with the sandstone, the ore solutions probably ascended along it and thence toward the surface along the steep shears. If so, cinnabar may have been deposited along the contact, particularly if it dips as gently as surface evidence indicates. Unless there is an unexpected steepening in the dip of the contact it should be not more than 200 feet below the No. 8 tunnel level, but because the contact may steepen and therefore be at much greater depth than 200 feet below No. 8 tunnel, its depth and nature should be explored by drilling in advance of sinking on or near the shears.

Star Workings. The Star workings of the Aetna mine are mainly on the No. 9 level (plate 37) and consist of several thousand feet of drifts and crosscuts, most of which are accessible. One filled winze extends at least 100 feet below the No. 9 level and some ore was stoped below this level, but the maximum depth of the Star workings is unknown. Conflicting reports give depths of from 100 feet to 1000 feet below the No. 9 level. The lower figure is probably the correct one. Above the No. 9 level are two small tunnels, the Skunk and Star tunnels, which were formerly connected with it by stopes. The vertical range of the Star ore bodies is at least 250 feet.

The country rocks are sandstone and shale (Franciscan) intruded by a few small dikes of olivine basalt. In this area the sediments have a low dip, but in the mine workings they are locally contorted and faulted. Probably none of the faults have much displacement, and some are little more than joints. Several small dikes of olivine basalt occur along the faults; in places sandstone breccia is welded by stockworks of basalt stringers.

There are two main ore-bearing structures, termed the Star and Morey veins. Both are mineralized faults along which there were widely spaced ore shoots. Other shoots occurred on splits from these faults. The Star vein strikes northeast and has an average dip of 60° northwest; the dip becomes vertical at the southwest end of the vein, where it joins the Morey vein. Three ore shoots were stoped along the fault and another at its intersection with the Morey vein. The northeastern ore shoot was the largest and probably extended to the Star tunnel, and possibly to the Skunk tunnel. The other shoots were smaller and ranged from 15 feet to 40 feet in length, although the one just southwest of the main shoot extends for an unknown distance below the No. 9 level. Traces of cinnabar along the fault between the stopes might open into ore shoots above or below the No. 9 level. Two mineralized faults, trending N. 10° E. and N. 20° E., respectively, lie just east of the Star vein. Stopes on the western fault are caved and nothing can be said of their shape and size. The easterly fault was stoped for a horizontal distance of 80 feet and vertically for at least 50 feet but not below the No. 9 level. Both of these faults contain small lenses and stringers of basalt. The Morey vein is a sheeted zone rather than a single fault. Its northern half trends about N. 45° W. and its southern half trends about N. 15° W.; the dip varies from vertical to 60° northeast. At its southern end the vein is lost among several small northeastward-trending faults. Small stopes are at several places along its length.

Further exploration in the Star workings should follow known ore-bearing structures on, and below, the No. 9 level. Particular attention should be paid to structures that contain basalt, because these are probably the most open and hence the most favorable.

Pope Workings. The Pope workings of the Aetna mine consist of two small isolated tunnels which lie northeast of the Star workings (see pl. 35). The East Pope tunnel is 117 feet below the West Pope tunnel. Apparently the East Pope tunnel has not been worked for many years, but ore was being stoped from the West Pope tunnel during the spring of 1943. This ore averaged about 3 pounds of quicksilver to the ton.

The Pope ore bodies are located along a poorly defined zone of shearing and brecciation which trends about N. 60° W. The rocks in this broken zone are sandstone, shale, and minor amounts of greenstone and chert (Franciscan). Cinnabar occurs as fracture fillings in lenses of chert, and the size and shape of the ore bodies are roughly determined by the shape and size of the chert lenses.

The East Pope workings are the smaller of the two. A little ore of unknown grade was removed from the one small stope, which is partly caved. It is doubtful if this stope extended below the tunnel floor. In December 1941 of the West Pope workings (see pl. 35) included one stope which measured 20 feet by 14 feet on the floor of the tunnel and extended about 40 feet to the surface. According to Conrad Martin, superintend-

ent of the Aetna mine, the West Pope tunnel has been extended 200 feet since examined by the writers. This development indicates that the ore body trends N. 30° W. at an angle to the general trend of the shearing. This ore body has been explored below the tunnel floor by a 25-foot winze. Showings of cinnabar occur on the surface near the West Pope tunnel and are partly prospected by shallow trenches and cuts.

Of all the mineralized areas in the Aetna mine, the Pope area is the most difficult to explore because of the lack of well-defined structures. Prospecting by open trenches and cuts to disclose the better surface showings, and sinking on these seems the most logical method of exploration.

Washington Shaft. The Washington shaft of the Aetna mine is southeast of the Phoenix workings (see pl. 35) and has been caved for many years. Its depth is unknown, but judging from the size of the dump it is probably several hundred feet. The collar is in serpentine, but according to old reports part of the shaft is in sandstone. Cinnabar reportedly occurred in silicified serpentine, but not in the sandstone.

Silver Bow Workings. The Silver Bow workings of the Aetna mine consist of three main adits (No. 2, No. 7, and No. 9 tunnels) and an unknown number of levels, sublevels, and stopes along the ore body. The ore body is intersected by the lowest tunnel (No. 9), 774 feet below the outcrop, and is reportedly explored by a winze about 100 feet below this level. Only a very small proportion of the workings were accessible at the time of the examination (see pl. 35), consequently, the following description is based largely upon data from old maps and published reports,[8] interpreted in the light of the few observations which could be made. The only ore mined from the Silver Bow workings in recent years was taken from the upper, near-surface, workings. Much of the 1942 production of the Aetna mine came from material on the Silver Bow dumps.

The Silver Bow ore body lies along the hanging wall of an olivine basalt dike, which strikes about N. 15° E. and has an average dip of about 45° east. The hanging wall contact of the dike rolls irregularly (see pl. 35). In most places a zone several inches to several yards wide of brecciated sandstone and shale (Franciscan) or black gouge, separates the basalt from the relatively unbroken sandstone. Along both the hanging wall and footwall contacts of the dike the basalt in most places is altered to a white plastic clay, which is locally several feet thick. Cinnabar occurs in the basalt and brecciated Franciscan rocks and also in small amounts along contraction joints in the dike (see pl. 35).

The localization, thickness, and grade of the ore shoots along the Silver Bow dike were most probably controlled by anticlinal rolls and flattenings of the dip of the hanging-wall contact. According to Bradley[9]

> "Above the No. 7 the vein was not over 3 to 4 feet wide and with a steep dip. At that depth it flattened out and widened to about 20 feet between walls, extending to the No. 9."

The geologic sections (pl. 35), although highly interpretive, show this flattening of the hanging wall and the probable position of the best

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[8] Forstner, William, The quicksilver resources of California: California Min. Bur. Bull. 27, pp. 72-76, 1903.
Becker, G. F., op. cit., p. 354, 1888.

[9] Bradley, Walter W., Quicksilver resources of California: California Min. Bur. Bull. 78, p. 78, 1918.

ore. As the data from which these sections were constructed are so incomplete, it would be pure speculation to point out other places where high-grade ore was mined, although it seems very possible that there were other, but smaller, high-grade shoots, which were likewise controlled by local rolls and flattenings of the hanging wall.

Only general recommendations for exploration can be made until the old workings are reopened. When this is done it will be advisable to carefully map the hanging-wall contact of the dike and the relative positions of the stopes, to obtain information useful in the search for ore shoots. The hanging-wall contact of the dike should be explored by drifts on the No. 9 level. The footwall of the dike has never been explored, and may be ore-bearing in places; however, the footwall is structurally not as favorable as the hanging wall, because it is probably less brecciated.

Aetna Extension Prospect

The Aetna Extension prospect, in sec. 34, T. 10 N., R. 6 W., is just north of the Silver Bow workings of the Aetna mine (see pl. 35). It was owned in 1943 by Atkins, Kroll and Company, of San Francisco. To the writers' knowledge no quicksilver has ever been produced from this property. It consists of two isolated tunnels, the No. 1 tunnel and the Rhodes tunnel, which total about 1,600 feet in length. The upper, or No. 1 tunnel, (see pl. 35) was driven 640 feet along the hanging wall of the Silver Bow dike, and the Rhodes tunnel was driven 1,000 feet southwestward with the intention of intersecting the dike at depth, an objective which was not realized. Much of the surface area above the No. 1 tunnel was stripped by bulldozer, and some cinnabar was found.

The No. 1 tunnel was driven in 1942 in an attempt to develop the surface showings of cinnabar uncovered by the bulldozer cuts. Although traces of cinnabar were found, there was nothing of commercial value. The geology is similar to that of the Silver Bow workings except that the dike is much thinner. The footwall of the dike was explored in two places and alteration of the basalt is similar to that along the hanging-wall contact.

The Rhodes tunnel was driven during the early history of the mining district, but was reopened during the winter of 1942. It is entirely sandstone and shale (Franciscan). At several places where shale is the dominant rock there is extensive brecciation and shearing. In one of these breccia zones are angular blocks of basalt, which are commonly altered to clay. The rocks at the face of the tunnel are badly sheared, and black clay gouge is abundant, which may indicate that the Silver Bow dike is near. Apparently no cinnabar was found in this tunnel.

Favorable ground for exploration lies along the hanging wall of the Silver Bow dike; therefore it is advisable to extend the Rhodes tunnel to the dike and drift along the hanging wall.

Ivanhoe Mine

The Ivanhoe mine (once called Mount St. Helena and also Patten claims), in sec. 34, T. 10 N., R. 6 W., consists of a few hundred feet of drifts and crosscuts and two stopes. It is owned by Atkins, Kroll and Company of San Francisco. The property joins the north edge of the Aetna Extension claim. There are two parts to the mine: the Patten tunnel, now inaccessible, lies to the west, and the main part of the mine

lies to the east. The country rocks are sandstone and shale (Franciscan) and a little olivine basalt. The rocks which enclose the ore bodies are highly brecciated and sheared, and have a northwesterly lineation. Angular fragments of basalt, altered to white clay, are scattered throughout the breccia.

In the main tunnel (pl. 35) are two small stopes. The larger extends at least 20 feet below the floor of the tunnel. Between 200 and 300 flasks of quicksilver were recovered from ore removed from these stopes. This ore probably averaged more than 10 pounds of quicksilver to the ton.

Valley Mine

The Valley (or Lidell) mine, in sec. 34, T. 10 N., R. 6 W., is the site of the original discovery of cinnabar in the Eastern Mayacmas district. The mine was abandoned before 1890 because of difficulties caused by carbonic acid gas and hot water. The mine is now flooded and mineral waters from the old shaft are piped to the Aetna Springs resort at the mine site. An unknown but probably small amount of ore was mined from silica-carbonate rock before the property was abandoned.[10]

Oat Hill Area

General Geology

The Oat Hill area, which is in Lake and Napa Counties, is near the eastern end of the mapped area and includes the Hardister prospect, James Creek placers, Oat Hill, Oat Hill Extension, and the Toyon mines. The principal structure in this area is the broad eastward-plunging Mayacmas anticline, the core of which is composed of sandstone and shale (Franciscan), and the flanks of shale (Knoxville) and of serpentine. Tuffs of the Sonoma volcanics unconformably overlie these rocks along the flanks of the anticline and Quaternary basalt flows unconformably overlie them as scattered patches along the crest. The mines lie along the crest of the anticline where the sandstone has been broken by normal faults. These faults, with few exceptions, strike northwest and dip northeast, and average 1,000 to 2,000 feet in length.

Mines

Hardister Prospect

The Hardister prospect (Rich Hill mine), in sec. 19, T. 10 N., R. 6 W., is about 2 miles west of the Oat Hill mine on Bucksnorter Creek in Lake County, and consists of a caved shaft and several small surface cuts. It is owned by Mrs. Doris Hardister, Middletown, California. A few flasks of quicksilver were produced by the owner during the first World War. The country rocks are kaolinized sandstone and shale (Franciscan). No cinnabar was observed in the dump material from the old shaft.

James Creek Placers

For over 30 years various miners have been concentrating cinnabar from the stream gravels of James Creek below the Oat Hill mine dumps. Winter rains annually bring down more cinnabar from the extensive Oat Hill mine dumps, and also reconcentrate the cinnabar in the creek gravels.

These placer operations have been carried on along James Creek for a distance of 2 miles below the Oat Hill mine dumps. No accurate

[10] California Min. Bur., State Mineralogist's Rept. 9, p. 68, 1890.

record of the production from these places is available but it must be several hundred flasks.

Oat Hill Mine

The Oat Hill mine, in secs. 27, 28, 33, 34, T. 10 N., R. 6 W., is 9 miles southeast of Middletown in Napa County. In 1944 it was owned by Norman Livermore and was formerly leased by the H. W. Gould Company, both of San Francisco. It was brought into production in 1876 by the Napa Consolidated Quicksilver Mining Company and continued uninterruptedly until 1910 when operations ceased because of the exhaustion of high-grade ore. It has yielded a total of more than 160,000 flasks of quicksilver—an amount exceeded in this country only by the New Almaden and New Idria mines. The workings, which probably total over 20 miles in length, underlie an area 1 mile long and half a mile wide and extend through a vertical range of about 1,000 feet. Only a few thousand feet of workings are now accessible, and since 1927 work has been confined mostly to a relatively small area in the southwest corner of the mine. Ore now consists of admixed stope fill and wall rock, which is treated in a 4- by 64-foot rotary furnace.

Most of the mine workings were inaccessible in 1943. Little is known of the mine workings inaccessible before 1906, at which time the mine maps were destroyed by fire during the San Francisco earthquake. A mine map made after 1906 shows the distribution of the workings then open and figure 3, which shows the principal veins, was compiled from this map. The geology and mine descriptions to follow are based upon the small amount of published data and a preliminary examination of the mine area made during parts of the summer and autumn of 1941 and 1942. A detailed report, based on work by another field party of the Federal Geological Survey will undoubtedly modify some of the present interpretations.

The ore bodies occur along a system of normal faults that, with few exceptions, strike northwest and dip northeast. In general, the faults are marked by a sandstone hanging wall that persistently carries a clay gouge and fragments of sandstone, and a sandstone footwall that is not usually so well developed, and in places dies out. Between the hanging-wall and footwall faults a block of mineralized sandstone occurs, which ranges from 5 to 40 feet in width and averages about 20 feet. The sandstone nearly everywhere in the Oat Hill mine area has been kaolinized by mineralizing solutions, and, in general, is soft and friable. Near the faults, where mineralization is most pronounced, the rocks are nearly white and are cut by numerous dense quartz veinlets. Cinnabar, associated with calcite and pyrite, is disseminated in fine crystals throughout the highly altered sandstone and is most widespread on the footwall side faults. Ore is less commonly present within the sandstone between the hanging-wall and footwall faults, and rarely above the hanging-wall fault. In such places the amount of ore is small.

In the footwall zone of the faults, flat-lying ore bodies, partly controlled by bedding planes, ranged from a few feet to as much as 100 feet long and 50 feet high. Ore bodies along each fault were, for the most part, confined to a central zone 200 to 600 feet long, 200 to 800 feet high, and from 5 to 100 feet wide. They attained their greatest depth in the Manzanita fault, and were mined to the surface in the Manzanita, Mercury, Fanny, Osceola, Humboldt, and possibly also in the Accidental,

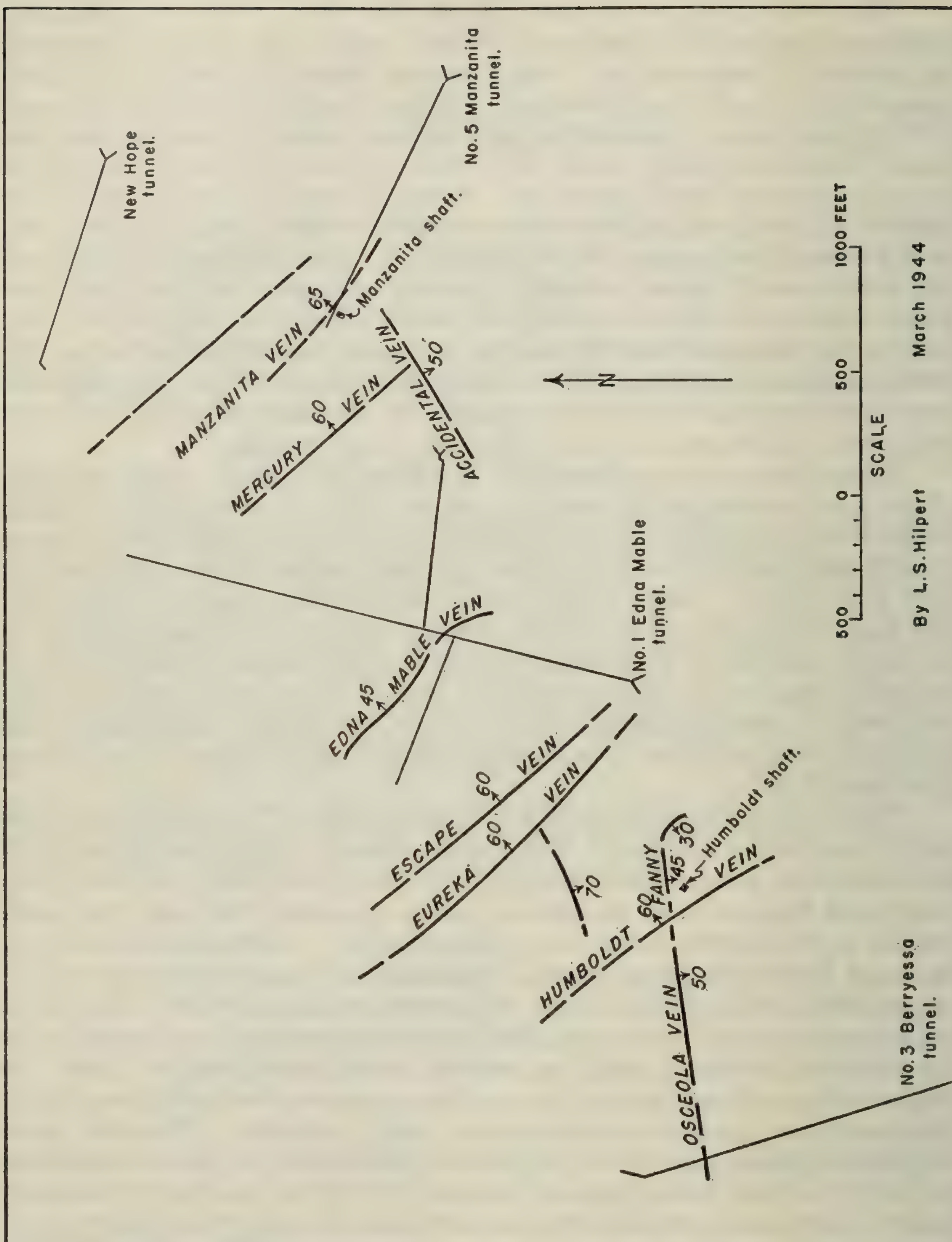

FIG. 3. Map of vein system at altitude of 1800 feet, Oat Hill mine, Napa County, California.

and the minor faults parallel to the Accidental and Mercury. The best ore generally occurred along the central parts of the faults.

Because the mineralization follows the faults, they are locally known as "veins". In this description the term *vein* is restricted to the mineralized zone between, and in, the walls of the fault; and the term *vein area* includes both the material between and in the walls of the fault, and also the mineralized wall rock.

The vein system of the Oat Hill mine is shown in figure 3. For convenience, the veins are divided into two groups. The southwest group includes the Edna Mable, Escape, Eureka, Humboldt, Fanny, and Osceola, and associated minor veins. The northeast group includes the Manzanita, Mercury, Accidental, and associated veins.

It was in the northeast group that quicksilver was probably discovered at Oat Hill in 1872. At the time of Becker's [11] visit (between 1883-85) this part of the mine was still the principal producer. The Manzanita and Mercury veins were most productive, and the Accidental was spoken of as only a prospect. The Manzanita had already been bottomed on the 750 level (about 1,100 foot altitude) and the Mercury had been bottomed on the 400 mine level (1450 foot altitude). Somewhat later work in the northeast group developed ore bodies along two or more low-dipping veins that split from the footwall of the Mercury.[12] These are not shown on figure 3, because of the uncertainty of their position and extent. The workings from the No. 2 Manzanita adit that trend N. 40° W. probably follow another vein, or a split from the Manzanita vein, but the only information obtainable for this area is conflicting, and the amount of material stoped and attitude of the supposed vein are problematic. There is general agreement, however, that the area within the acute angle of this supposed vein with the Manzanita contained a large ore body.

First work done in the southwest group of veins was in the early eighties. Becker [13] speaks of the development of a minor deposit on the Eureka claim along a well defined fault nearly at right angles to the Mercury and Manzanita. This was undoubtedly the Osceola vein. Work in the southwest group continued without interruption until 1910, when the high-grade ore bodies of both the northeast and southwest groups had been exhausted, and the mine shut down. Later work, during the last World War, by Murray Innes, developed some small ore bodies along the Accidental and in some of the minor veins parallel to the Accidental and Mercury veins. In 1927 the H. W. Gould Company leased the property and continued operations to the present. In 1930 a 4- by 64-foot rotary furnace was installed, and since that time production has been maintained by mining admixed low-grade stope fill and caved wall rock from the Osceola vein and parts of the Humboldt near its intersection with the Osceola.

This material is being removed by top-slicing methods, which have proved to be more economical than the old square-set methods formerly employed on this property. Of special interest is the fact that in parts of the areas now being mined material is being reworked for the second time. For the period from August 1939 to March 1943, 83,250 tons of

[11] Becker, G. F., op. cit., pp. 356-358, 1888.
[12] Forstner, William, op. cit., fig. 29, p. 89, 1903.
Becker, G. F., op. cit., p. 358, 1888.
[13] Becker, G. F., op. cit., p. 358, 1888.

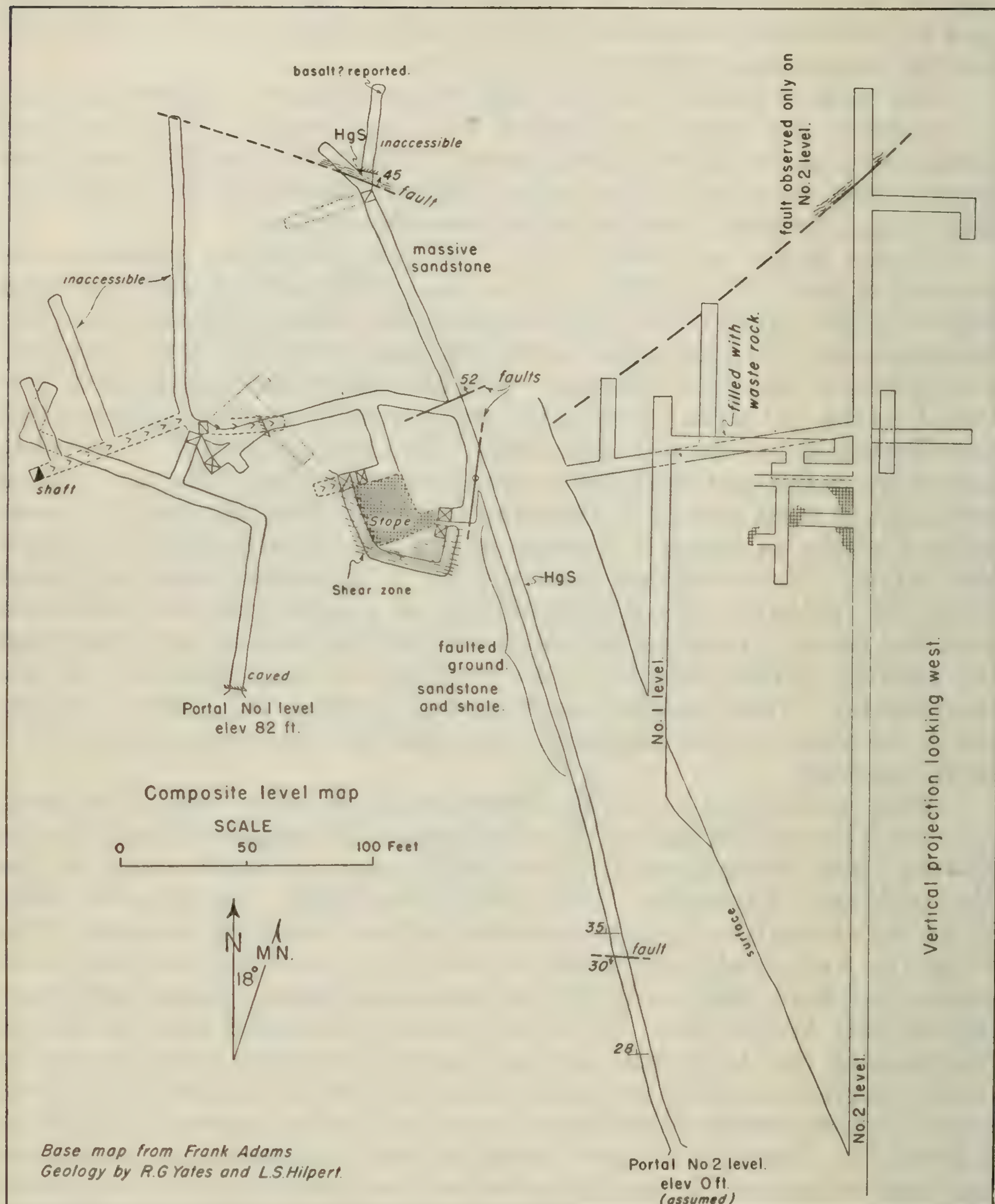

FIG. 4. Map and projection of Toyon mine, Napa County, California.

ore were treated, yielding 3527 flasks of quicksilver for an average grade of 0.16 percent of quicksilver per ton. In the year 1898, 32,489 tons of ore were treated for an average yield of 0.80 percent. The grade for the years 1876-1910 probably averaged between 0.75 and 1 percent per ton, although old records indicate an average grade of 2 percent for the years 1879-80.[14]

Oat Hill Extension Mine

The Oat Hill Extension mine (sometimes called Anderson), in sec. 27, T. 10 N., R. 6 W., which was visited during the autumn of 1941, adjoins the Oat Hill mine along its eastern side. It is owned by Zack Anderson, of Middletown, and has been in operation intermittently since 1932. The workings, which total only several hundred feet in length, are probably in the southeastern end of the Manzanita vein where it extends beyond the Oat Hill mine property. The ore, which is similar to that now being mined from the Osceola vein of the Oat Hill mine, is treated in a retort after being concentrated on a jig.

Toyon Mine

The Toyon mine (formerly the Granada, also Switzer mine), in sec. 34, T. 10 N., R. 6 W., is located about a mile southeast of the Oat Hill mine. It was opened in 1929, but the first recorded production was not until 1933. Since then the mine has had a small and erratic production. It is owned by Frank Adams of Pope Valley. There are two sets of workings, the Granada and Toyon. The Granada tunnel was inaccessible during the time of the field work but reputedly is several hundred feet long. The Toyon workings (fig. 4) consist of an inclined shaft, two main levels, and several sublevels. The upper levels were inaccessible in December 1941, but most of the lower (No. 2) level was open, as well as the sublevel immediately above it. Only the Toyon workings are described below.

The country rocks are sandstone and shale of the Franciscan group. The sandstone is hydrothermally altered to a soft gray rock. The main ore body is in a northwestward-trending zone of disturbed and faulted rocks, and another, unexplored, ore body is along a fault which strikes N. 70° W. and dips 45° north. Neither of these faults can be traced on the surface. The main ore body pitches steeply to the east. It has been stoped only above the lower level; hence nothing is known of its downward continuation. Cinnabar occurs as crystals disseminated in altered sandstone and along fracture planes.

Further exploration should include the determination of the downward extent of the ore body. Other ore bodies may exist along the strike of the fault that cuts the northern end of the No. 2 tunnel (fig. 4).

Corona-Twin Peaks Area

General Geology

The Corona-Twin Peaks area, in Napa County, which includes the Corona and Twin Peaks mines, is on the south flank of the Mayacmas anticline, opposite the Oat Hill mine. Both mines are in the same serpentine body as the Phoenix workings of the Aetna mine (pl. 29). The rocks are serpentine, silica-carbonate rock, sandstone, and shale of the Franciscan group, and tuffs of the Sonoma volcanics. The prevailing dip of the rocks and structures that control the ore bodies is to the south.

[14] Palmer, Lyman L., History of Napa and Lake Counties, California, p. 170, 1881.

In this area the northern border of the serpentine body is a discontinuous and irregular ledge of silica-carbonate rock, in which is located the Corona mine. About a quarter of a mile south of this ledge is a parallel ledge of silica-carbonate rock, in which is located the Twin Peaks mine. Both ledges have been broken by minor late fault movements.

Mines

Corona Mine

The Corona mine, in secs. 32, 33, T. 10 N., R. 6 W., began production in 1895. It is about 10 miles by graded road from Middletown, and can also be reached from Calistoga via the Livermore Ranch road. The Vallejo Quicksilver Mining Company, Vallejo, California, operates the mine. The mine was active between 1895 and 1906, and intermittently from 1941 to 1943. The workings (shown on pl. 38) consist of about 2 miles of drifts, crosscuts, and adits. One of the three main ore bodies was worked partly by an open pit. Less than 10 percent of the Corona workings were accessible during 1941 and 1942; consequently, descriptions below are based upon old mine maps and published reports, supplemented by observations on the surface and in the accessible part of the mine.

The silica-carbonate rock ledge that encloses the ore shoots of the Corona mine strikes N. 65° W. and dips, on an average, about 45° southwest. Its contact with the underlying Franciscan rocks is a thrust fault, the silica-carbonate rock being thrust over the Franciscan rocks and locally over tuffs of the Sonoma volcanics. Its contact with the overlying serpentine, although gradational, is fairly sharp. The ledge has an average thickness of about 75 feet. According to an old map the ledge is intersected by a drain tunnel 700 feet vertically below the outcrop. The ledge is broken by two sets of joints, one roughly parallel to the strike and dip of the ledge and the other, which is vertical, at right angles to the strike of the ledge. The ledge rock is dominantly dark green to black opaline silica. Cinnabar occurs as dark red crystals disseminated through it and as crystalline coatings on fracture faces. Locally the ore contains over 10 percent pyrite, which makes it difficult to treat in the furnace.

There were at least three separate ore shoots in the Corona mine; all were in silica-carbonate rock and all pitched southwest. The stopes of the ore body near the No. 2 tunnel were inaccessible, but the upper parts of the other two ore bodies were examined. The largest ore body was in the vicinity of the No. 1 and No. 3 tunnels and was worked from the surface to a depth of at least 440 feet. All stopes below the No. 3 level were inaccessible, but their probable form is shown on plate 38. On the No. 3 level this ore shoot was stoped for a length of almost 100 feet and a width of about 50 feet, and the open cut on the surface is of comparable size. In 1902 according to Forstner,[15] this ore shoot was "opened for a length of 160 feet and has been persistent from the surface to the present depth of 450 feet." In 1941 another ore shoot was discovered on the surface about 250 feet east of the open pit. This ore shoot is probably the same as that on the No. 2 level just east of the winze that goes down to the 1853-foot level. All that is known of the southeast ore shoot (near No. 2 tunnel) is shown on plate 38. If it continues to pitch in the same direction it probably joins the main ore shoot about the

[15] Forstner, William, op. cit., p. 79.

1,853-foot level. The ore shoot exploited by the Bluff tunnel is the smallest of the three. It was mined for a stope length of 160 feet, mostly below the Bluff tunnel level.

As shown by the cross-sections (pl. 38) almost all the Corona ore shoots formed neither along the hanging walls nor footwall of the silica-carbonate ledge but well within the ledge. Possibly this relationship is not true in the lower, inaccessible, part of the mine or in the southeast ore shoot, but it is true in all accessible parts of the mine. It is evident, therefore, that future exploratory work should not be restricted to either the hanging wall or footwall, but should include also the central parts of the ledge. Silica-carbonate rock ledges in other parts of the district should be explored in a similar manner.

The writers are unable to evaluate future prospects of the Corona mine because of the lack of information pertaining to the inaccessible parts of the mine. Any development program should be started by reopening the No. 2 tunnel and the drain tunnel. Perhaps there is still considerable ore about the old stopes in the inaccessible parts of the mine, for recent operators were able to mine low-grade ore, at and near the surface, which was left by the original operations.

Twin Peaks Mine

The Twin Peaks mine, in sec. 4, T. 9 N., R. 6 W., was first operated in 1902. It is about three-quarters of a mile southeast of the Corona and is owned by Louis D. Fay of Oakland. Since its early producing years (1902 to 1907, inclusive) the mine has had two periods of activity, namely during the first and second World Wars. The property consists of about 4,200 feet of adits, drifts, and crosscuts (pl. 39), most of which were inaccessible during the examination. There are three main adits, the Lawley, Retort, and Wilson tunnels. All the ore came from the Wilson tunnel.

The mine is in a silica-carbonate rock ledge, which fingers out into unaltered serpentine near the southeastern limit of the workings. In addition to silica-carbonate rock and serpentine, there are numerous veins and lenses of white to greenish-white clay, tentatively determined as saponite. This clay is not an attrition product, or gouge, but was formed by hydrothermal alteration of serpentine. It is older than the silica-carbonate rock, and, therefore, was potentially able to exert a control both on the distribution of the silica-carbonate rock and the cinnabar. According to Mr. L. D. Fay,[16] the owner, a clay vein in the Wilson tunnel formed the hanging wall of the ore shoot. The silica-carbonate rock resembles that in the Corona mine, particularly where it carries cinnabar. The serpentine is both sheared and massive; some dunitic phases include disseminated crystals, lenses, and stringers of chromite. In the south crosscut of the Retort tunnel (not accessible in May 1943) it is reported that the silica-carbonate rock contains needles of millerite and that samples of the rock assayed from 0.50 to 5.85 percent nickel. In the accessible workings none of the sandstone and shale of the Franciscan group that occurs southwest of the ledge was cut.

Only one ore shoot was exploited in the Twin Peaks mine; however, cinnabar has been found in at least one other place. Reportedly, it occurs in the silica-carbonate rock cut by the crosscut which trends N. 35° E. from the Contact drift (see pl. 39). The old stope of the Wil-

[16] Fay, Louis D., personal communication.

son tunnel ore shoot was partly reopened in November 1941, and some ore was mined. This shoot is apparently localized along steep northwesterly cross fractures under a vein of clay. The Retort tunnel was driven to intersect the Wilson ore shoot 44 feet below the Wilson level, but failed to find a downward extension of the ore body. As there is no evidence of post-cinnabar faulting, it is doubtful if the Wilson ore body is faulted off. More likely, it either ''bottoms'' above the Retort level or pitches toward an unexplored area.

Further exploratory work at the Twin Peaks mine should include a search for a downward continuation of the Wilson ore shoot and exploration of the cinnabar-bearing ground in the Contact drift.

Mirabel-Great Western Area

General Geology

The Mirabel-Great Western area is in the center of the Eastern Mayacmas quicksilver district and includes the Great Western and Mirabel mines, as well as several smaller mines. All the deposits are within a narrow belt along the northern border of the large serpentine mass that extends across the southern part of the mapped area (pl. 29). The regional dip of the serpentine mass is to the south, but at three places tongues of serpentine extend into the Franciscan rocks. The tongues of serpentine are roughly anticlinal, the axes of the anticlines lying parallel to the main trend of the serpentine mass. One is just east of the Mirabel mine, another is between the Great Western mine and the Otto Bullion mine, and a much smaller tongue is adjacent to the Bullion mine. The Franciscan rocks are sandstones, shales, and cherts, intruded by greenstone (not shown separately on plate 29). West and south of the Great Western mine are several exposures of shale, which probably belong to the Knoxville formation, but these are not adjacent to the quicksilver deposits, nor are the tuffs of the Sonoma volcanics, which overlap the serpentine. West of the Great Western mine several fairly large bodies of gabbro intrude the serpentine and shales (Knoxville). The serpentine directly associated with the ore bodies is altered to silica-carbonate rock, and much of the sandstone (Franciscan) within the area is kaolinized.

Ore bodies in the Mirabel-Great Western area occur in silica-carbonate rock, in sandstone of the Franciscan group, and in chert. Both numerically and economically the silica-carbonate rock deposits are the most important. The chert-type ore bodies were found only in the Old Great Western mine, which is no longer accessible. The sandstone-type deposits are small and as yet of no economic importance.

Prospecting in this area should be in silica-carbonate rock along the serpentine boundaries and in sandstone in places where it is kaolinized.

Mines

Bullion Mine

The Bullion mine (old Northwest mine), in sec. 23, T. 10 N., R. 7 W., is located about 3½ miles south of Middletown. It was discovered sometime before 1893 and apparently abandoned in 1903. It was worked in conjunction with the Mirabel mine, and the production figures were probably included in those of the Mirabel mine. As judged from the size of the stopes, it probably produced several thousand flasks of quicksilver. The mine, which was inaccessible at the time of the examination, was developed by one main shaft, several smaller shafts, and about half a

mile of drifts, crosscuts, and winzes (see pl. 40). The main (No. 2) shaft was 400 feet deep, and some stoping was done as far down as the 400-foot level. From surface observations and interpretation of the mine map (pl. 40) it appears that the ore body of the Bullion mine was in silica-carbonate rock at a serpentine-sandstone (Franciscan) contact. The ledge of silica-carbonate rock that contained the ore shoot strikes about N. 45° W. and dips about 50° northeast.

Great Western Mine

The Great Western mine, in sec. 21, T. 10 N., R. 7 W., is located about 4 miles by paved highway and dirt road southwest of Middletown. It was opened in 1873 and has since produced over 100,000 flasks of quicksilver, a production exceeded by only six other mines in the United States, and by only one in the Mayacmas district. The mine was worked almost continuously up to 1911, when it was abandoned as worked out. From 1911 to 1931 the only production came from the old dumps, but in 1931 mining was resumed and has continued to the present. It is owned by the Richard Detert estate of San Francisco and is operated by Bradley Mining Company of San Francisco.

As shown on plate 41*A* the mine is divided into two parts, referred to as the Old Great Western and the New Great Western, respectively. At the time of the examination the Main shaft of the Old Great Western mine was flooded, and workings that connected with the other half of the mine were caved; consequently, descriptions of much of the mine are based upon old published reports.[17] Some of the early workings, which were examined by Becker, have been reopened by modern workings near the present furnace; however, that part of the mine, known as the Old Great Western, developed after Becker's visit and before 1912, is inaccessible. In the aggregate, the Great Western property consists of about 8 miles of workings distributed through a vertical distance of over 750 feet.

Old Great Western Mine. The Old Great Western mine, now wholly inaccessible, consists of six main levels and an unknown number of sublevels. The workings were formerly accessible by a shaft 700 feet deep and by a drainage tunnel 500 feet below the shaft collar and 2200 feet long. According to an old map, ore was stoped on the 700-foot level and ground was explored at least 50 feet below this level by a winze.

The general trend of the workings is about N. 45° W., which is probably the general trend of the mineralized ground. This direction corresponds with the major controlling structure of the ore body, namely, the contact between the serpentine and Franciscan rocks. The serpentine along this contact is partly altered to silica-carbonate rock, but the ore in this part of the mine was in chert (Franciscan). Chert and greenstone are locally the dominant constituents of the Franciscan group in this area. Cinnabar occurred as small veinlets and as coatings on fracture faces of the chert.

No information was obtained concerning the size and grade of the ore shoots and the structures that controlled them. Probably the shoots were comparable in size and grade to those described by Becker (see pl. 41*A*, cross-sections). The structural features which controlled the

[17] Becker, G. F., op. cit., pp. 359-362.
Forstner, William, op. cit., pp. 52-55.
California Min. Bur., State Mineralogist's Rept. 12, p. 361, 1894.

distribution of the ore shoots were probably gouge seams, minor faults, and the shape, size, and fractured character of the chert lenses.

The Old Great Western workings reputedly were abandoned because of the forced closing of the drainage tunnel by a court injunction, ordered on the opinion that mine drainage water contaminated St. Helena Creek and thus decreased the value of land along it. Re-opening of the drainage tunnel would undoubtedly permit extraction of a considerable tonnage of ore that was of too low grade to be mined by earlier operations.

The Elmer tunnel, southeast of the main workings of the Old Great Western mine (see pl. 41*A*), was being re-opened in May 1943. According to Mr. Hazen Crabtree, superintendent of the Great Western mine, a little cinnabar was found near the end of this tunnel by the "old timers." Between this tunnel and the southeast end of the main Old Great Western workings (see pl. 41*A*), along the strike of the serpentine-Franciscan contact, there are over 500 feet of unexplored ground that may contain ore shoots. The surface between the Main shaft and the Elmer tunnel is almost completely covered by landslide and slope-wash detritus so that the geology could not be ascertained. The silica-carbonate rock ledge shown on plate 29 is probably continuous across this area, and the part of the ledge now covered by detritus may well be the source of the cinnabar-bearing blocks of silica-carbonate rock mined from the foot of a landslide farther down the valley. The fact that no ore was mined from the exposures of silica-carbonate rock in this valley favors the premise that the silica-carbonate rock ore in the landslide was derived from a part of the ledge now covered by detritus.

Some ore was being mined by open pit from the above-mentioned landslide in May 1943. Most of the cinnabar-bearing material is concentrated at the bottom of the pit in a nearly horizontal layer, covered by an overburden of 10 to 30 feet of barren landslide material. The cinnabar occurs in blocks of silica-carbonate rock and in the mud matrix of the slide. The cinnabar is crystalline only in the centers of the larger silica-carbonate rock blocks; it is a soft clay-like material in the outer, weathered, parts of the blocks.

New Great Western Mine. The New Great Western mine includes the modern workings of the Great Western mine as well as some of the earliest workings described by Becker. The workings accessible in 1942 included two main levels below the haulage tunnel (No. 2 tunnel) and several minor levels above it. These workings extend 200 feet above the No. 2 tunnel and over 175 feet below it. Incorporated in the modern part of the mine are workings driven before 1900. Many of these are so badly caved that no attempt has been made to reopen them; others have become part of the modern workings.

The New Great Western mine is in a zone of sheared and brecciated rocks, which represents a faulted intrusive contact between serpentine and rocks of the Franciscan group. The Franciscan rocks include sandstone, shale, and chert; the serpentine includes silicified and silica-carbonate phases. All the rocks are broken; some by tight shears, others by open fractures. Plate 41*B* illustrates the sheared and brecciated character of the rocks. In some places the contact between serpentine and brecciated Franciscan rocks is sharp; elsewhere the two breccias are separated by a zone of rocks of both types. Becker's vertical cross section (pl. 41*A*) oversimplifies the relationships, but as many of the work-

ings on which the section was based are inaccessible, it is not possible to make accurate corrections, and the section is therefore reprinted essentially unchanged. The area shown as silica-carbonate rock including a thin stringer of serpentine could be more accurately shown as a breccia zone composed of sheared serpentine, shale, and sandstone, with included, irregular bodies of silica-carbonate rock.

The ore occurs as pipe-like shoots in the silica-carbonate rock. Some of the old stopes are as much as 500 feet high, 160 feet long, and 50 feet wide, but none of the modern stopes are this large. Some ore shoots extended to the surface, others pinched out below the surface, and still others extended neither to the surface nor to the lower levels of the mine. Several stopes extend below the lowest (X) level of the mine, but because of water conditions little work has been done there. Some ore shoots mined during recent years were overlooked by the early operators; others may have been left as being too small or too low grade to mine, but this is doubtful as the average grade of ore mined in 1893 contained 15 pounds of quicksilver to the ton, or only 3 pounds more than the average ore mined during 1935. The average for 1893, however, may not represent that period, and part of the ore mined during that year may have been extracted from ore shoots of a different type in the Old Great Western workings.

Cinnabar occurs in the ore shoots as veinlets and as crystals disseminated in the silica-carbonate rock. In the veinlets it is associated with opal, quartz, dolomite, calcite, and pyrite. Hydrocarbons, in the forms of oil and tar, are commonly associated with the metalized rock, and are a useful guide to ore.

In this part of the Great Western mine the ore shoots are controlled by fractures and faults, by slivers of black alta, or by a hanging-wall contact of silica-carbonate rock. These minor structures generally strike in a more northerly direction than the general N. 60° W. trend of the breccia zone.

The future of the Great Western mine depends upon (1) downward extension of the known ore shoots, (2) finding ore in the inaccessible Old Great Western mine, and (3) finding new ore shoots between the main shaft and Elmer tunnel. Reopening of the drainage tunnel is essential before the first two possibilities can be explored. The third possibility is probably the brightest hope of the Great Western mine.

Joyce Prospect

The Joyce prospect, in sec. 14, T. 10 N., R. 7 W., is about three quarters of a mile northwest of the Mirabel mine, on State Highway 29. Two small shafts represent the development work on this property, and a small, unrecorded amount of quicksilver has been produced. The country rock is altered sandstone of the Franciscan group. Cinnabar occurs as crystals disseminated in altered sandstone, as at Oat Hill. The controlling structure appears to be a northeast-trending fault, although it can not be definitely traced across the property.

Midway Mine

The Midway mine, in sec. 17, T. 10 N., R. 7 W., is on the south fork of Dry Creek, about 4 miles by road from Middletown. It was first worked in 1930, but cinnabar has been known in the area from a much earlier date. It is owned by Elbert J. Wilkinson of Middletown. The workings consist of several short tunnels and shallow open cuts (see fig.

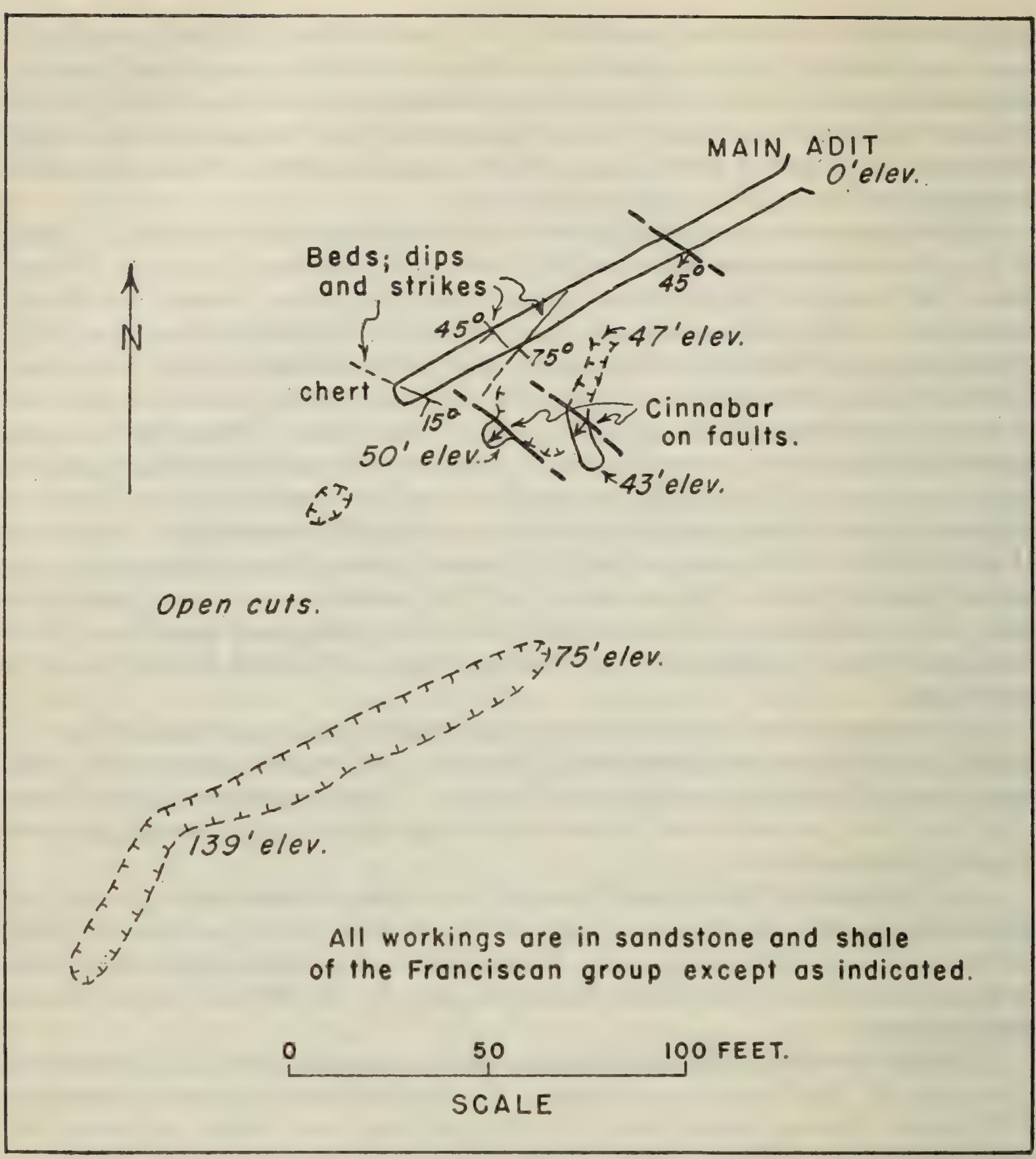

FIG. 5. Geologic sketch map of Midway mine, Lake County, California.

5). The ore is concentrated on a table and the concentrates burned in a small retort.

The country rocks are sandstone and shale plus a minor amount of chert, all of the Franciscan group. The general strike of the rocks is northwest and the general dip is southwest. Several minor faults of both northeast and northwest strike cut the sedimentary rocks. Cinnabar occurs as impregnations in the sandstone along the northeast faults. The area immediately east of the mineralized ground is covered by a landslide, which may conceal an extension of the deposit. It would be expensive, however, to explore beneath this slide. In May, 1943, the Midway mine was still in the prospect stage with no definite ore shoots developed. The most logical method of development is to sink on the mineralized faults that control the cinnabar distribution.

About half a mile east of the Midway mine are several short prospect tunnels which explore a small silica-carbonate rock ledge that strikes east and is surrounded by serpentine. The ledge is broken by cross fractures, which dip steeply northeast and strike northwest. No cinnabar was seen.

Mirabel Mine

The Mirabel mine (formerly Bradford mine), in sec. 23, T. 10 N., R. 7 W., was discovered in the early seventies, and is the fourth largest mine in the Mayacmas district. It is in the valley of St. Helena Creek about 4 miles south of Middletown, by State Highway 29. The mine consists of two separate sets of workings, the Great Eastern workings on the east side of St. Helena Creek and the Bradford workings on the west side (see pl. 29). The original discovery was made on the east side of the creek, but the early workings were soon flooded and the mine abandoned. At a later date this area was reopened and became the Great Eastern mine (Great Eastern workings). During its early years the Mirabel mine was very productive, but by 1898 the ore reserves were believed depleted and the mine was abandoned. In 1930, the present operators, the Mirabel Quicksilver Company of Middletown, by a well planned and executed program of development and exploration, returned the mine to production, and have kept it there ever since.

In May 1943 the Mirabel mine was worked from two main shafts; one, a 350-foot vertical shaft, develops the Great Eastern ore body, and the other, a 300-foot vertical shaft, develops the Bradford ore body. The two sets of workings are not connected. The Great Eastern ore body was explored 500 feet below the collar of the shaft, but in May 1943 the workings below the 275 level were flooded. The Bradford workings are open to the 300 level and below this level are caved.

The Mirabel mine lies at the border of the large serpentine mass that stretches across the southern part of the mapped area and is in a zone of faulted and sheared Franciscan rocks cut by several irregular dikes of serpentine. The Franciscan rocks include sandstone, shale, chert, and greenstone. Most of the rocks are altered locally: the sandstone is softened through kaolinization, or hardened through silification; the greenstone is converted to a white clay, or is altered to a sheared chloritic rock, which strongly resembles serpentine; and the serpentine is altered to silica-carbonate rock or partly silicified to a transitional facies between serpentine and silica-carbonate rock. Minor shears, faults, and breccia- and gouge-zones are common and apparently all are of pre-mineral origin. Some fractures, notably those in silica-carbonate rock, are filled, or partly filled, with coarsely crystalline white dolomite.

Cinnabar occurs in the silica-carbonate rock in ore shoots of both tabular and pipelike forms. The largest shoot, a tabular body, was at least 240 feet long, 20 feet wide, and 200 feet high. The ore shoots are elongated in directions which range from N. 0°-30° W. and most of them pitch to the south. The footwall is commonly brecciated sandstone and shale, accompanied in most places by a thin layer of black alta. Hanging walls are usually absent, the silica-carbonate rock usually grading into unaltered serpentine.

The ore minerals, listed in decreasing importance, are cinnabar, metacinnabar, and native mercury. Associated with them are pyrite and hydrocarbons, and veinlets of dolomite and quartz.

Bradford Workings. The Bradford workings consist of about 2 miles of drifts, crosscuts, shafts, and raises (see pl. 42). The two main levels, the 120 and 300, connect directly with the Bradford shaft; the principal intermediate level, the 180, is not directly connected with the shaft. The extensive "Old West Stope" workings below the 300

level (south of the Bradford shaft) are inaccessible. Ore has been mined from two areas, one south of and the other northwest of the Bradford shaft. The area south of the shaft includes the Old West and East stopes (inaccessible), and the area northwest of the shaft includes the 120, Vineyard, and September stopes, as well as several smaller stopes.

In this part of the Mirabel mine there are at least two serpentine dikes; both strike north and dip steeply east. The larger dike is over 100 feet wide and contains most of the Bradford ore shoots. This dike pinches to the north and widens to the south. It is completely altered to silica-carbonate rock in the vicinity of the Old West stope and sporadically silicified and altered to silica-carbonate rock in the vicinity of the 120, Vineyard and September stopes, which, although small in contrast to the Old West and East stopes, yielded ore of good grade. The Vineyard and September stopes do not extend to the 300 level. Several small ore shoots have been discovered on the 300 level, and these may extend both upward and downward. There is 150 feet of unexplored ground above them.

The Old West stope, now mostly inaccessible, is the largest in the Mirabel mine. In May 1943 it was being reopened and old stope fill was being burned in the furnace. The Old West ore shoot had a strike of N. 20° W. and an average dip of 45° east. The dip flattened locally, especially at the 245 level. On the 300 level it is joined by the East stope, and a little below this level it becomes two small pipe stopes which extend to the 400 level. It is not known if production between 1894 and 1898 came from this part of the mine. The structural control of the Old West ore shoot could not be determined from the small amount of workings open in May 1943.

The East ore shoot extended from the surface to the 300 level, where it intersected the Old West ore shoot. It was a pipelike body which pitched 30°, S. 20° E. This stope was not seen.

Great Eastern Workings. The Great Eastern ore body is exploited to a depth of 500 feet by a vertical and an inclined shaft and by several thousand feet of drifts and crosscuts. When the mine was visited in 1941 and 1943 it was flooded below the 275 level. The two main ore shoots (No. 1 and No. 2), extended from the surface to the 500 and 465 levels, respectively (see pl. 43). According to Thomas O'Conner a little ore remains in the flooded part of the mine, but probably not enough to warrant removal.

The Nos. 1 and 2 ore shoots are nearly parallel, pitch 45° south, and trend N. 50° W. and N. 10° W., respectively. They are in silica-carbonate rock at its footwall contact with brecciated sandstone and shale. Above and away from the ore shoots the silica-carbonate rock grades to unaltered serpentine. Several small stopes mined in the lower levels may represent the "roots" of the deposit.

The common ore mineral is cinnabar. Metacinnabar, however, occurs as the principal ore mineral in a projection of the No. 2 ore shoot, about half-way between the 150 and 275 levels. This is the only place in the Mirabel mine where metacinnabar is known to occur in appreciable amount and the only stope of east-west trend.

Future of the Mirabel Mine. The Mirabel mine, abandoned in 1898 as exhausted, was returned to production in 1930 through a well planned

and executed exploration and development program. Its current production is mostly from near the old workings, but new ore shoots are continuously being discovered. Future production is most likely to come from ground as yet relatively unexplored. One promising unexplored area lies between the Bradford and Great Eastern workings and another is between the Bradford workings and the drill hole prospect southwest of the Bradford shaft. As both of these areas are covered by recent stream gravels, surface prospecting by pits and trenches is neither effective nor economical. Possibly the area between the Bradford and Great Eastern workings could be most effectively explored by core drilling from the Bradford 300 level. The area southwest of the Bradford shaft is larger, and hence more difficult to explore; drilling this area from the surface seems to be the most economical method of exploration.

Otto-Bullion Mine

The Otto-Bullion mine, also known as the Otto mine, is located in sec. 22, T. 10 N., R. 7 W., 5 miles south of Middletown and adjacent to the Bullion mine. In April 1944 it was being operated by the Bradley Mining Company of San Francisco, California. It is owned by the Otto family. Development work consists of a 163-foot shaft and two levels, which total 270 feet in length. Small cinnabar veinlets occur in silica-carbonate rock near a sandstone contact. No ore body has been developed in this mine.

Plymouth Mine

The Plymouth mine, in sec. 24, T. 10 N., R. 7 W., is part of the Mirabel Mining Company property. It is about a quarter of a mile southeast of the Great Eastern shaft of the Mirabel mine. Development consists of 2500 feet of horizontal and vertical workings (see pl. 44), over half of which were open in May 1943. The lower (No. 1) tunnel and the two shallow shafts were inaccessible. A small but unknown amount of ore was mined from the open pit at the portal of the No. 2 tunnel. In May 1943 the operators were attempting to develop a tonnage of low-grade ore in the No. 2 tunnel.

The mine workings explore cinnabar-coated fractures in a tabular body of silica-carbonate rock. The silica-carbonate rock is south of the main serpentine-Franciscan contact and is surrounded by serpentine. Cinnabar occurs as crusts on joint surfaces, where it is associated with opal. There are two well-defined systems of joints; one set strikes N. 10°-20° E. and dips steeply west, and the other strikes N. 60° W. and dips 20°-40° southwest. Cinnabar is distributed along both sets.

Helen-Chicago Area

General Geology

The Helen-Chicago area, on the east slope of Pine Mountain at the head of Dry Creek, includes the Helen, Chicago, Wall Street, Jewess, Research, and Bacon Consolidated mines. The Helen mine, credited with over 6000 flasks of quicksilver, is the most productive mine of this group.

The gangue rock of all these mines is serpentine altered to silica-carbonate rock. The deposits are all within the same intrusive mass and most of them are located well within the borders of the intrusion. The Helen mine, however, is at the contact between serpentine and Franciscan rocks. The Bacon Consolidated mine is in a tongue of serpentine

nearly isolated from the main mass. The prevailing structural trend is N. 60° W. and the prevailing dip is south.

The quicksilver deposits belong to the silica-carbonate rock type. Silica-carbonate rock is common in this area as vein-like and tabular bodies, most of which strike about N. 60° W. and dip south. The ore shoots are both tabular and pipe-like. Cinnabar is found as veinlets filling fractures and as crystals disseminated in the silica-carbonate rock. Native mercury is a common accessory mineral. Pyrite and marcasite are abundant in some of the ores. Hydrocarbon compounds are common and are useful guides to ore.

Mines

Chicago Mine

The Chicago mine (formerly known as the St. Louis, the Pittsburg, and also the Ural mine), in sec. 1, T. 10 N., R. 8 W., is on Dry Creek about 6 miles by road southwest of Middletown. It is owned by F. G. Johnson, G. N. Johnson, G. M. Hobson, and G. H. Hobson, and is under the management of F. G. Johnson, of Yountville, California. Although discovered prior to 1865, the mine has never been an important producer of quicksilver. Forstner[18] mentions 125 flasks having been produced prior to 1903, but other records indicate the first production was in the year 1903. One record indicates a production of 599 flasks in 1906, which is undoubtedly an error for old residents and mining men of the district have informed the writers that the Chicago property was idle during that year. Furthermore, it is doubtful if such a large production could have been taken from the small stoped area in the mine. The last production for the property, 9 flasks, was made in 1942 when it was under lease to W. B. Coffey, of El Cerrito, California. Total production is probably less than 150 flasks.

The mine consists of over 1500 feet of drifts, crosscuts, and shafts (see pl. 45). The main shaft (150 feet deep) and bottom level were caved in July 1943. These workings are illustrated on plate 45 from descriptions of several mining men in the district. About half the remaining workings were accessible.

The mine is in a silica-carbonate rock ledge, which strikes northwest and dips about 55° southwest. The ledge is 18 to 25 feet thick and can be traced 700 feet northwest of the mine, where it pinches out. To the southeast it cannot be traced beyond Dry Creek. It does not connect with the ledge of either the Helen or the Research mines. The only exploited ore shoot is in the center of the silica-carbonate ledge near its southern end; this was worked from the surface through a vertical distance of 80 feet to the Lower tunnel level, where it was bottomed. It pitches west on a slight roll in a shear in the silica-carbonate rock. This shear is in the center of the ledge and is probably the fracture along which hydrothermal solutions first formed the silica-carbonate rock and then deposited the ore minerals. The ledge is broken by numerous fractures which strike with the ledge and dip about 45° northeastward and are mostly filled with late carbonate veins. Cinnabar is the common ore mineral, but native mercury is abundant locally. Both minerals generally occur as a narrow seam along parts of the shear, but in the ore shoot, cinnabar was disseminated for a few feet along both sides of the shear.

[18] Forstner, William, op. cit., p. 51.

Ore reserves in the Chicago mine are almost negligible. Some marginal ore is reported to occur along the shear in the inclined shaft (collar altitude 2694), but the quantity is probably small. A few "colors" were reported on the bottom level at the foot of the respective raises and near the northeast face, and only occasional traces of cinnabar were noted along the Lower tunnel level.

Helen Mine

The Helen mine (formerly American, and Dead Broke), in sec. 1, T. 10 N., R. 8 W., which was mapped in June and July, 1943, is 7 miles west of Middletown, Lake County, California. It was discovered before 1871 and was opened in 1873. Since then it has been worked intermittently by various owners and lessors. It is owned by Klau Mine, Incorporated, under the management of H. W. Gould, of San Francisco, and is under lease to L. S. Peterson, Bob Franklin, Al Rogsted of Middletown, and S. J. Kline of Calistoga. Except for the year 1876, there is no record of production until 1903. Total recorded production to 1942 is 6,851 flasks of quicksilver. The plant, which is half a mile by road from the mine, includes a 3- by 35-foot rotary furnace that is not in condition for immediate operation. The workings, most of which are old and inaccessible, consist of over 5,000 feet of tunnels on three principal levels. These are the Main, or 400-foot level, the Santa Maria, or 300-foot level, and the Peterson No. 4, or 70-foot level. Several intermediate workings include the Beatrice, Rocca, Dike, and San Juan tunnels (see plate 46).

The rocks in the mine area consist of sandstone of the Franciscan group and serpentine separated by a northwest-trending fault, which dips about 35°-40° to the southwest (see plate 47). A discontinuous ledge of silica-carbonate rock occurs along the footwall of the fault. This ledge is extremely irregular in plan, ranging from a few feet to about 150 feet in thickness, and is partly covered by a landslide in the central part of the mapped area. It is apparent, however, that the ledge pinches rapidly where it is covered by the south edge of the slide, and it is reported that the ledge was not continuous on the 400 level under the slide.

Tertiary or Quaternary basalt dikes, now completely altered to a soft, white clay, were intruded into the serpentine and along the main fault prior to the formation of the silica-carbonate rock. A remnant of a basalt flow or intrusion caps part of the ridge in the northern part of the mapped area. There was no observed connection between this body and the altered dikes, but they are believed to be related because of their similar composition. Moreover, this basalt overlies the main fault, along which some of the dikes occur. There are no other Tertiary or Quaternary basalts in this part of the Mayacmas district.

Most of the ore bodies in the Helen mine were in silica-carbonate rock. However, some ore has been mined from the altered basalt dikes, and some was reported to occur in the sandstone hanging wall in the No. 2 crosscut of the 400 level. The silica-carbonate rock ranges from greenish, somewhat silicified serpentine cut by fine carbonate veinlets, to a dense, black, opaline rock containing much pyrite and little carbonate. Ore generally occurs in the black opaline rock, usually as small veinlets and disseminations of cinnabar. Although cinnabar is the only important ore mineral on the property, small amounts of native quicksilver are found in some of the ore bodies, and metacinnabar has been reported in

moderate amounts near the surface in the silica-carbonate ledge above the San Juan tunnel. Tiemannite, the selenide of mercury (HgSe), has been reported in this mine, but none was observed by the writers. Cinnabar disseminations in basalt dikes made up a large part of the No. 3 ore shoot, parts of the West pit, and some of the 70-level ore body (see plate 46).

At least one of the larger ore bodies in the Helen mine occurred at a point of flexure in the main fault, as exemplified by the terrace-like flexure over the No. 2 ore shoot. The location of smaller ore bodies usually was controlled by inverted troughs produced by intersection of minor faults, or by intersection of faults and dikes. Control within the dikes is not clear, but some of the ore probably occurred below constricted parts of the dikes.

Little is known about the size, shape, and distribution of the ore bodies of the No. 1 ore shoot as all the workings in that part of the mine have been inaccessible for several years. It has been reported, however, by Andrew Rocca, Jr., former manager of the mine, that a large percentage of the silica-carbonate rock has been stoped between the surface and the sublevel below the San Juan tunnel and throughout most of the width of the ledge. This information is substantiated by Forstner's [19] account of a crosscut tunnel penetrating 120 feet of ledge, of which 100 feet was ore-bearing. The tunnel he refers to is undoubtedly the Beatrice (altitude 2,613 feet) in which the richest ore is reported to have occurred along the footwall of the ledge at that level and to have become poorer in grade as it approached the hanging wall. The 20 feet next to the hanging wall at this level were reported to be barren. Some ore was taken from along the hanging wall of the ledge at the surface, and along the San Juan tunnel, and an unknown amount came from the ledge along the hanging wall immediately above the San Juan sublevel. Below this sublevel the ledge was either barren or too low grade to mine.

Ore shoot No. 4 is a local term applied to two or more unconnected ore bodies. This shoot consists, at least in part, of one ore body mined in the early 1930's from the 70 level to the surface, and another which was being explored along the 300 level during July 1943. Exploratory work in the intervening area consisted of two 30-foot raises driven from the 300 level, an inclined raise being driven from the north end of the 300 level, and a 40-foot winze and crosscut under the 70 level. The 70-level ore body is probably controlled by a northward-trending premineral fault, which dips steeply to the west and offsets the main fault. The 300-level ore body lies between a steeply dipping basalt dike and a low-angle minor fault, which is probably subsidiary to the main fault. The silica-carbonate rock, in which the ore occurs, follows the footwall of the subsidiary fault westward until it disappears. From near the point where this fault disappears the silica-carbonate rock lenses out between the fault and the basalt dike.

The footwall of the main fault has been explored only a short distance west of the No. 1 raise on the 300 level, because the workings were driven along the subsidiary fault in the mistaken belief that it was the continuation of the main fault. When the true nature of the subsidiary fault became known, two 40-foot drill holes were driven from the 300 level southward toward the main fault, but failed to reach it. It is believed by the writers that west of the No. 1 raise, below a terrace under

[19] Forstner, William, op. cit., p. 56.

the 70-level workings, the strike of the main fault swings. The structure resulting from this terrace and swing in strike provides sufficient control for the localization of an ore body (see sec. A-A, pl. 47).

According to Mr. Rocca the silica-carbonate rock under the main fault pinched out along the 400 level on both sides of the No. 2 ore shoot. However, as silica-carbonate rock was probably localized under the terrace above the No. 2 ore shoot, it may occur similarly under the terrace near the 300 level.

It is suggested therefore that the footwall of the main fault be considered for exploration south and west of the face of the 300 level. If silica-carbonate rock should be found at, or a short distance below this level, it should be followed down the dip to the point where the fault resumes its normal regional dip of 35°-40°. If an ore body occurs in this area, it will probably be found immediately below the terrace along the steep part of the fault. If the fault plane does not steepen, it would be inadvisable to explore below the 400 level, for in general this marks the lower limit of ore in the mine.

A small reserve of low-grade ore was in sight in 1943. Along the 300-level ore body of No. 4 ore shoot, 70 grab samples taken by the mine operators in 1941-42 indicated 3,500 tons of ore averaging 5 pounds of quicksilver per ton. Of this, 2500 tons were reasonably assured. In addition, there is reasonable expectation of about 5000 tons of inferred ore averaging about 5 pounds per ton around the peripheries of the 300-level ore body and the western end of the sublevel below the 70 level. According to L. S. Peterson, a former operator of the property, some ore was left on the 400 level of the No. 3 ore shoot. Some marginal ore probably occurs around the peripheries of the stopes of the No. 1 ore shoot, and in the sandstone of the hanging wall along the No. 2 crosscut of the 400 level. An unknown amount of low-grade ore, probably mostly submarginal, occurs in parts of the several basalt dikes in the mine.

The average grade of ore produced by the Helen mine has been estimated by former operators at between 10 and 12 pounds of quicksilver per ton. According to Mr. Rocca, 913 flasks were taken in 1916 from the No. 2 shoot from a total of 9000 tons of ore, for an average of about 8 pounds per ton. The grade for the 70-level ore body also averaged about 8 pounds per ton. Averages for the rest of the mine are problematic, but it is likely that the ore bodies of the No. 1 ore shoot averaged close to 20 pounds of quicksilver per ton of ore.

Bacon Consolidated Mine

The Bacon Consolidated mine (formerly Barnum mine), in secs. 11, 12, T. 10 N., R. 8 W., is on the crest of the Mayacmas Range about half a mile south of Pine Mountain. It was discovered in 1859 or 1860,[20] and by 1865 had a few hundred feet of shallow workings. It reputedly produced about 300 flasks of quicksilver during the years 1876 and 1877, but has since been abandoned. It is now merely an assemblage of caved adits and brush-covered pits and trenches. The size of the dumps indicates that the mine was never extensive. Several ledges of silica-carbonate rock cross the area, and the ore was apparently in this material.

[20] Widmann, Adolph, Report in prospectus of the Lake Valley Quicksilver Mining Company, p. 11, 1865.

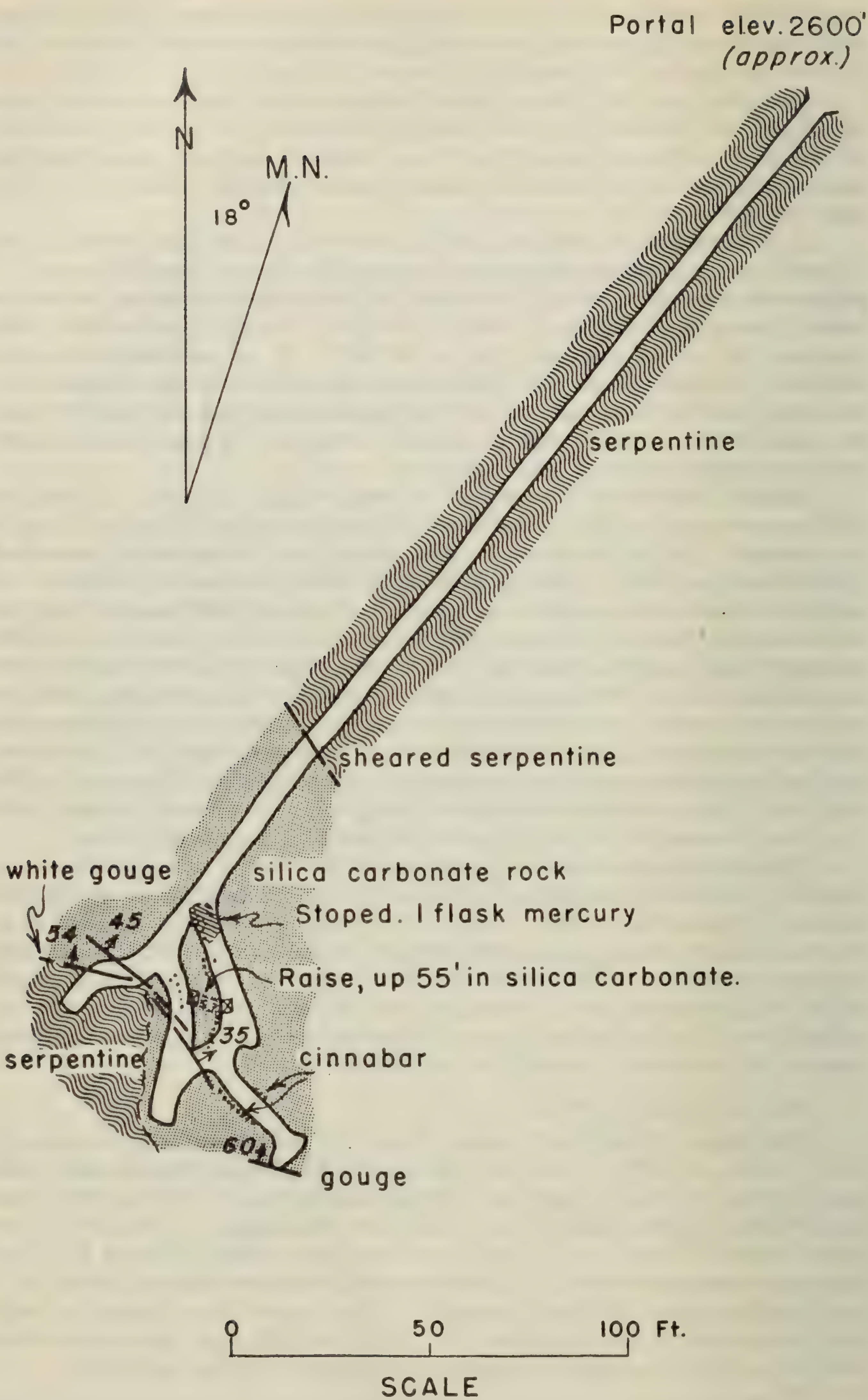

Fig. 6. Geologic map and section of the Research mine, Lake County, California.

Jewess Mine

The Jewess mine, in sec. 1, T. 10 N., R. 8 W., is about 4 miles southwest of Middletown and about 1 mile east of the Helen mine. It consists of an open pit and two short tunnels, which were caved in September 1941. Mining men in the district estimate that there was a total production of about 60 to 100 flasks of quicksilver from this property. The open pit is in a ledge of silica-carbonate rock which trends northwestward.

Research Mine

The Research mine, in sec. 1, T. 10 N., R. 8 W., is on the south side of Dry Creek about 6 miles by road southwest of Middletown. In July 1943 it was claimed by Otto Koopman and Fred Herman of San Francisco and Middletown, California, respectively. In 1941, when most of the development work was done, it was leased by W. B. Coffey, of El Cerrito, California. Workings (see fig. 6) consist of about 400 feet of drifts on one adit level and a raise, about 55 feet high, from the level. Some years ago a lower adit, called the Bridge tunnel, was driven from near the bottom of Dry Creek ravine about 500 feet S. 59° W. under the present site of the Research mine workings.

The ore occurs in a silica-carbonate rock ledge in serpentine, which strikes about N. 30° W. and dips steeply northeastward. This ledge lies between the Helen and Chicago mines, but has no connection with the silica-carbonate rock bodies of either of them. Cinnabar, the ore mineral, occurs in spotty disseminations along with much pyrite in the silica-carbonate rock. A few ''colors'' are reported from near the face of the Bridge tunnel which is said to have penetrated 60 to 70 feet of silica-carbonate rock. In 1943, when the mine was inactive, a few ''colors'' were observed in the upper workings, but there was little in sight that could be considered ore.

Wall Street Mine

The Wall Street mine (formerly the Nevada and also the Cincinnati mine), in sec. 1, T. 10 N., R. 8 W., is about 5 miles by road from Middletown and about three-fourths of a mile east of the Chicago mine. It is owned by Guy W. Hansen of Concord, California. Cinnabar was discovered prior to 1865, and the first recorded production was made in 1875. The total production is probably less than 400 flasks of quicksilver. Almost all the workings were inaccessible during the field work. Reputedly, the main mine is 90 feet deep, and the size of the dumps indicates that it must have several thousand feet of workings.

The workings are in a ledge of silica-carbonate rock, which strikes north and dips about 30° west. According to McCaskey,[21] ore averaging from 6 to 10 feet thick was found above and below a thin quartz vein. This vein was from half an inch to 1 inch thick and was parallel to the dip of the ledge.

The silica-carbonate rock ledge enclosing the Wall Street ore body is not connected with any other mineralized ledge in the area, nor is it a faulted segment of any other ledge. The ore mineral is principally cinnabar, with locally large percentages of native quicksilver.

[21] McCaskey, H. D., Mineral Resources U. S., Pl. 1, p. 940, 1912.

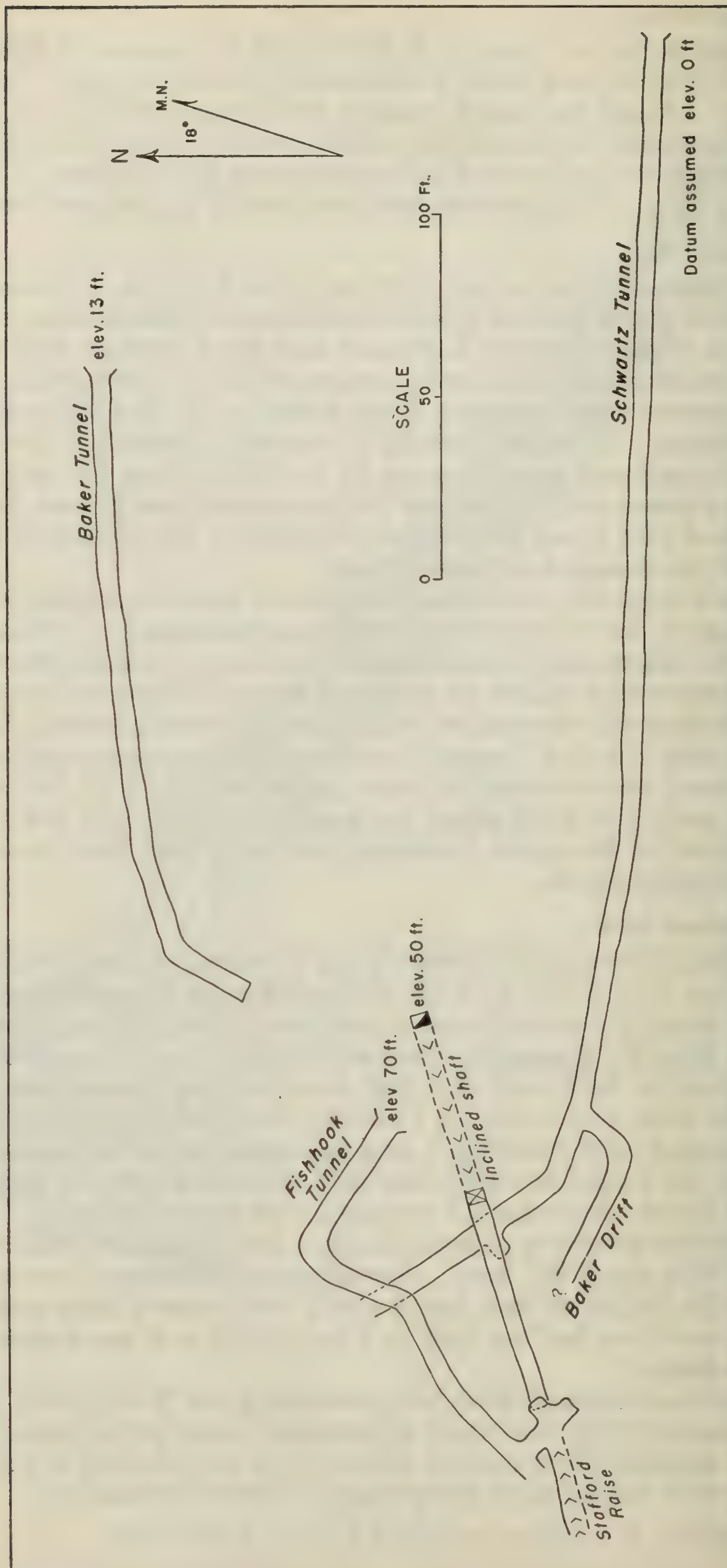

FIG. 7. Map of workings of Anderson mine, Lake County, California, modified from Company map.

Anderson Springs Area

General Geology

The Anderson Springs area is in the extreme western end of the district (see pl. 29). It includes four mines: the Anderson, Big Chief, Big Injun, and Thorne. All have produced a little quicksilver but none has produced over a few hundred flasks.

This area is off the trend of the main quicksilver belt, and is not associated with any large serpentine mass, as are most of the other areas. The dominant rocks are sandstone, shale, chert, and greenstone of the Franciscan group. There are several small bodies of serpentine, but for the most part these lack the northwesterly elongation characteristic in other parts of the district. Faults of diverse trends are common, but because of the heavy cover of vegetation and soil it was not possible to trace any single fault for more than a few hundred feet.

Several hot springs are active in the Anderson Springs area, and extensive areas of kaolinized sandstone suggest that hydrothermal activity has persisted for a long time. The mine waters of the Anderson, Big Chief, and Big Injun mines are warm and have a strong odor of hydrogen sulphide. Ancestral waters of these springs may have deposited the quicksilver minerals at an earlier time, but more probably the present waters are chemically different than those which formed the quicksilver deposits.

The ore deposits are apparently all in the Franciscan rocks, although a silica-carbonate rock ledge was prospected at the Big Injun mine. Cinnabar occurs as grains disseminated in the altered sandstone and in small veinlets of opal. The observed ore shoots are associated with fault and breccia zones.

Prospecting and exploration of the Anderson Springs area are handicapped by a heavy cover of soil and vegetation and downward development of the deposits will be handicapped by high temperatures. No large or promising ore bodies have yet been discovered in the area, and none of the mines has measurable ore reserves.

Mines

Anderson Mine

The Anderson mine, in sec. 25, T. 11 N., R. 8 W., is about 5 miles by paved and graveled road west of Middletown and about a quarter of a mile south of the Anderson Springs resort. In 1943 it was owned by H. H. Barrows, of Oakland, California. The mine consists of several short adits and open cuts (see fig. 7). Production was first recorded in 1929; and since then the mine has produced 187 flasks of quicksilver. It was inactive in 1943.

When the property was visited in December 1941, only part of the workings were accessible, and, unfortunately, none of the stoped ground. The country rock is kaolinized sandstone of the Franciscan group. Ore was found along two faults; one strikes about N. 60° W. and dips northeast; the other strikes about N. 60° E. and dips steeply northwest. These two faults apparently intersect near the Stafford raise, where some ore was found.

Surface exposures are too poor to determine the strength or continuity of the ore-bearing structures, and the inaccessibility of the underground workings prohibits a fair evaluation of the property. High temperatures are a handicap to deeper exploration.

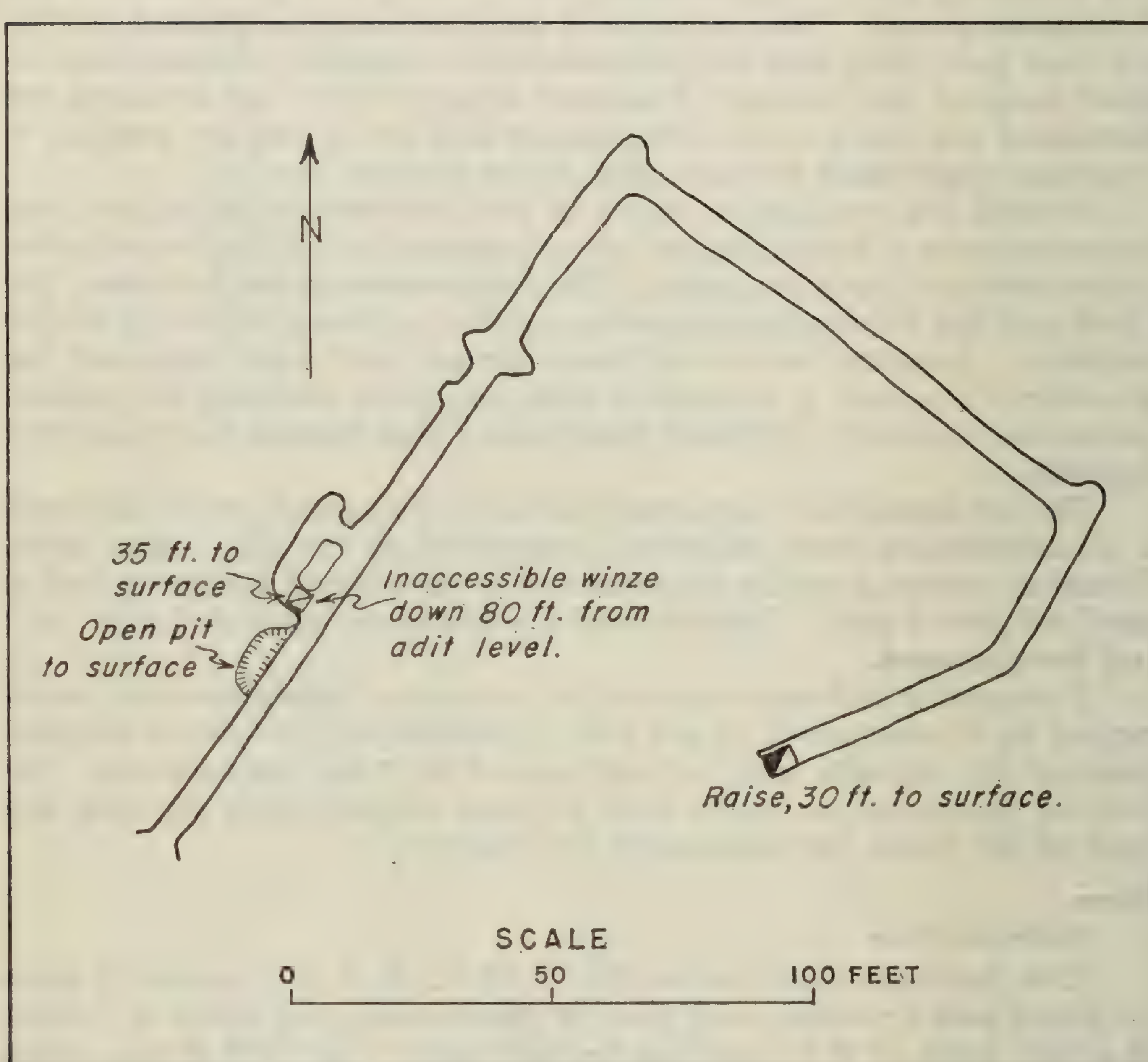

FIG. 8. Sketch map of Kellett mine, Napa County, California.

Big Chief Mine

The Big Chief mine, in sec. 36, T. 11 N., R. 8 W., is about 5½ miles by paved and graveled road west of Middletown, and adjoins the Anderson mine. It is owned by H. H. Barrows, of Oakland, California. This property first produced quicksilver in 1916, although cinnabar was found in the vicinity many years before. Since 1916 several operators have worked the property with varied success. The last attempt was in 1942, when a small pit was opened. Total recorded production up to 1941, inclusive, was 323 flasks of quicksilver, most of which (197 flasks) was produced in 1918. Most of the production was from surface workings, but the mine includes several thousand feet of adits, nearly all of which were caved in May 1943.

The country rocks are sandstone and minor amounts of chert, both of the Franciscan group. Several fault and breccia zones cross the property, and apparently the ore shoots were associated with these. Cinnabar occurs as crystals disseminated in the sandstone and as seams along partings and cracks in the chert. A considerable amount of 10- to 20-pound ore was mined from the property.

Big Injun Mine

The Big Injun mine, in sec. 35, T. 11 N., R. 8 W., is about a mile southwest of the Big Chief mine, but in May 1943 the road connecting these mines was impassible. The Big Injun mine is owned by Mrs. Alice (Fisher) Armstrong, of Calistoga, California. The size of the mine dumps suggests that there are about 1,000 feet of drifts and crosscuts, but only a small percentage of these workings are open, as the mine was abandoned over 20 years ago. Although the deposit reputedly was discovered in 1873, there was no production recorded before the first World War. In 1916-17, 250 flasks of quicksilver were produced for the total known production.

The mine was developed by three tunnels at different levels, all driven westward. According to published records[22] there are two mineralized zones, each about 30 feet wide, which strike northwest and dip northeast. The ore was in brecciated sandstone and shale (Franciscan) at the contact with a silica-carbonate rock ledge. On the surface this ledge trends about N. 20° W. and is bounded on the west by a breccia zone.

Thorne Mine

The Thorne mine (once known as Bear Canyon), in sec. 36, T. 11 N., R. 8 W., is about 6 miles by road west of Middletown and about half a mile south of the Big Chief mine. It was discovered prior to 1909 and was intermittently active until 1929, with a reported production of about 500 flasks. It has been idle during recent years. In 1943 it was owned by H. H. Barrows, of Oakland, California. The property consists of a few short adits, trenches, and pits. The workings are in a north-trending zone of kaolinized sandstone (Franciscan), which is probably controlled by faults, although no fault of any magnitude could be traced across the property. The ore apparently consisted of crystalline cinnabar disseminated in the altered sandstone.

Miscellaneous Mines and Prospects

Outside the mapped area (pl. 29) and yet close enough to be included in the Eastern Mayacmas district, are several other occurrences of cinna-

[22] Forstner, William, op. cit., p. 50.

bar. One of these is in serpentine at the contact with shales of the Knoxville formation, and the other two are in Sonoma volcanics. These deposits were only superficially examined.

Flynn Prospect

The Flynn prospect is about 3 miles northeast of Calistoga and a short distance west of the old Pope Valley toll road. It is owned by Miss Mary E. Flynn of Calistoga, California. It consists of several short adits that have been driven into tuffs of the Sonoma volcanics. No cinnabar was seen in the adits or dumps.

Kellett Mine

The Kellett prospect, in sec. 7, T. 8 N., R. 6 W., is about 1½ miles south of Calistoga immediately west of State Highway No. 29. In 1942, it was owned by S. W. Kellett, of Calistoga. The workings (fig. 8) consist of about 350 feet of drift along one adit level, and an 80-feet inclined winze. An unknown, but probably small, amount of workings extend from the bottom of this winze.

The entire workings are in tuffs of the Sonoma volcanics, cut by thin veinlets of opal. Cinnabar occurs as ''painty'' coatings along joints and seams throughout explored areas. Since its discovery in the seventies, a number of people have attempted to develop an ore body but without success. Because of the white translucent character of the tuff, a small content of cinnabar is likely to convey a false impression of its true worth. The best material probably averages less than 1 pound of quicksilver per ton. There is no record of past production, but it is probable that a few flasks were produced.

Whitney Mine

The Whitney mine, in sec. 21, T. 10 N., R. 5 W., is in Snell Valley, 10 miles southeast of Middletown. This mine consists of two shallow shafts and an unknown amount of underground workings, which were flooded in December 1941. A few flasks of quicksilver were produced from this property. The shafts were sunk near the contact between serpentine and shale (Knoxville).

MINERALS AT "THE GEYSERS," SONOMA COUNTY, CALIFORNIA

By M. Vonsen*

INTRODUCTION

Situated in northeastern Sonoma County, California, is the old health resort known as "The Geysers." The resort buildings are located on the south side and about 50 feet above Big Sulphur Creek, where the first buildings are said to have been erected in 1852. The locality has become widely known and has been visited by many people from this country and abroad, some to partake of the various natural mineral waters and hot baths which have become widely known for their curative properties, and others to see the so-called geysers. The name "geysers," however, is a misnomer, as there are none in the area; but there are fumaroles, many small steam jets and hot springs where water quietly boils, all producing large volumes of steam which, in the early morning or on a cool day, presents a scene that reminds one of Dante's Inferno.

The Geysers may be reached over a scenic and very good mountain road which leaves the Redwood Highway about a mile north of Healdsburg. The distance from Healdsburg to The Geysers is 25 miles. Another road leads in a southeasterly direction along Big Sulphur Creek from Cloverdale to The Geysers; but it is not in as good condition nor is it as scenic as the Healdsburg road.

At a point on the north side of Big Sulphur Creek directly across from the resort buildings is the mouth of Geyser Creek, a tributary of Big Sulphur Creek which extends in a northerly direction through a rather deep gorge for about half a mile, where it branches into two small streams which continue on up the mountain.

Beginning at a point about 50 yards up Geyser Creek from its mouth is the hot ground, a large solfataric area which extends up to the forks of the creek, a distance of about 400 yards. In this solfatara, on both sides of the creek and extending well up both sides of the canyon, the hot springs and fumaroles occur, the hot springs being mostly near the creek bed and the fumaroles and innumerable small steam jets extending from the creek bed well up the steep walls of the canyon. On a warm day the escaping steam from the smaller vents is hardly noticeable but in cold weather great volumes of steam can be seen quietly escaping from the hot ground on both sides of the canyon, presenting rather an unusual sight.

About a quarter of a mile west of Geyser Creek are other patches of hot ground where steam escapes, but with less violence. This may be designated as Lemonade Spring area. About half a mile farther west is another area of thermal activity known as Sulphur Banks. This is off the map (pl. 48).[1] At both these localities steam escapes from the barren hot ground in a great many places, and many small solfataras dot the areas. About 4 miles in an easterly direction from Geyser Creek is the Little Geysers area, once a fumarolic region, where a number of hot springs are continually bubbling and a few mud pots can be seen. Between the Little Geysers and The Geysers there are three lesser hot spring areas.

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* Honorary Curator of Mineralogy, California Academy of Sciences, Golden Gate Park, San Francisco. Manuscript submitted for publication July 22, 1946.

[1] Map adapted from Allen, Eugene Thomas, and Day, A. L., Steam wells and other thermal activity at "The Geysers," California: Carnegie Inst. Washington Pub. 378, fig. 1, 1927.

East of Geyser Creek for a distance of 300 or 400 yards are a number of steam wells constantly blowing off great volumes of steam with a roaring, hissing noise that from a short distance is almost deafening. The wells have 8- to 10-inch steel casing sunk to a depth of 200 to 400 feet, the intention being to utilize the steam to drive turbines for the development of electrical energy. This work was done in 1924-25 and there seems to have been no diminution of steam pressure over the years. It is still hoped this great source of energy will be utilized.[2]

THE SULPHATE MINERALS

During the summer and fall months of 1939 and 1940 many trips were made by the writer to The Geysers for the purpose of collecting the different minerals there for identification. This presented quite a problem, as there were acres of ground more or less covered with sulphate salts of various kinds. In order to simplify the sampling and recording of results, the area was first mapped (see pl. 48); thereafter, each sample was numbered as taken, and the number entered on the map. Plate 48 can not be considered complete, however, for not all of the minerals collected have been identified, and among the unidentified samples there may be some new mineral species. Also, it is hoped that minerals not yet collected may sometime be found, for this great natural laboratory is capable of producing a large variety of compounds. All these salts are easily soluble and disappear after the first heavy rains. More than 100 samples were collected and those affected by climatic conditions, particularly during the damp winter months, were placed in airtight containers for preservation.

Sulphate minerals of "The Geysers"

Mineral	*Found at locations*
Alunite $K_2Al_6(OH)_{12}(SO_4)_4$	26, 27
Alunogen $Al_2(SO_4)_3.18H_2O$	4, 6, 12, 17
Boussingaultite $(NH_4)_2SO_4.MgSO_4.6H_2O$	2, 3, 7, 9, 12, 16, 21
Cupro boussingaultite	15
Epsomite $MgSO_4.7H_2O$	1, 4
Gypsum $CaSO_4.2H_2O$	
Halotrichite $FeSO_4.Al_2(SO_4)_3.24H_2O$	8
Halotrichite, containing nickel	6
Mascagnite $(NH_4)_2SO_4$	3, 5, 10, 11, 19, 23, 24
Melanterite $Fe_2SO_4.7H_2O$	
Tschermigite $(NH_4)Al(SO_4)_2.12H_2O$	12, 15, 18, 20, 22, 24, 25
Voltaite $3(K_2,Fe)O.2(Al,Fe)_2O_36SO_3.9H_2O$	15
Unidentified	3, 6, 7, 13, 14

The following sulphate minerals from Geyser Creek Canyon and the hot ground near Lemonade Spring and Sulphur Banks were identified: mascagnite, boussingaultite, tschermigite, alunogen, epsomite, halotrichite, alunite, voltaite, melanterite, gypsum.

Mascagnite, a sulphate of ammonia, is quite generally distributed in the upper half of Geyser Creek Canyon, as incrustations and nodular forms, some with coarse, fibrous interior. It occurs where the ground is hot, even at the highest point in Geyser Creek Canyon near the Devil's Pulpit, on the eastern border of the hot ground. A great many small lumps of this mineral may be found there over an area of several hundred square

[2] Allen, E. T., and Day, A. L., op. cit.

feet. It is particularly noticeable in the early summer months but in late summer and fall it disappears, leaving a dark brownish residue. Its greatest development in larger firm, crystalline masses is near Lemonade Spring, where it is especially noticeable on the east bank of a small wash where specimens are removed with difficulty on account of the intense heat of the ground. Sulphur forms freely along with it, and in one spot cinnabar was attached to the under side of specimens. The mineral also occurs at Sulphur Banks, about half a mile farther west.

Another ammonium sulphate mineral which occurs in quite hard lumps was found in a number of places in Geyser Creek Canyon, but its identity is not yet known. It is white, porcelainlike in appearance, and very difficultly soluble in hot water, the solution being neutral; whereas mascagnite is readily soluble and yields a strongly acid solution.

Two ammonium iron sulphate minerals were found in the Lemonade Spring area, also not yet identified. One is light yellowish green in color, optically uniaxial with negative character, index of refraction 1.53. Before the Bunson burner it is volatile, leaving a heavy residue of iron. The other is pure white in color, optically biaxial and positive, index of refraction 1.525. It is not volatile, is difficultly fusible, and becomes magnetic after being heated before the reducing flame. It was first thought one of these minerals might be ammonia jarosite but preliminary work on it would indicate another compound. The two minerals are always attached, the yellowish-green mineral forming as a crust over the white material. At several places in Geyser Creek Canyon thick crusts of boussingaultite were found to be covered on the surface with a light yellowish mineral 2 to 5 millimeters in thickness, which proved to be an ammonium sulphate with some iron. Optically it differs from the other ammonium sulphates.

Boussingaultite is found in many places in Geyser Creek Canyon. It is particularly noticeable under the overhanging rock in the main creek about 200 feet south of the Devil's Pulpit below a point known as Lovers Leap. Here many square yards are crusted over with this mineral, and in places small stalactites 6 to 8 inches in length hang from the ceiling. This mineral seems to be confined almost entirely to Geyser Creek Canyon, its greatest distribution being in the upper end of the canyon. At Sulphur Banks boussingaultite was found in only one or two places. One would expect it to be a common mineral there, as the solfatara is in serpentinized rocks which, through hydrothermal action, have become badly altered. Serpentine is not in evidence at Lemonade Spring and boussingaultite was not found there.

On the east bank of Geyser Creek, across from the Devil's Arm Chair, and at several other places farther up the canyon, a light purplish colored mineral was found. It is an ammonium sulphate with chromium. Its index of refraction is the same as that of boussingaultite. It is probably chromiferous boussingaultite. At Witches Cauldrons on the west bank of Geyser Creek, crusts of boussingaultite, 1 to 2 inches in thickness, contain copper, which produces a bluish-black color on the surface and light greenish color in the interior. Some of the black surface coating is a copper sulphide. The light greenish cupriferous interior has the optical properties of boussingaultite.

Tschermigite in crusts and crystalline masses occurs in several places in upper Geyser Creek Canyon and near Lemonade Spring. In the latter

place fine crystallized tschermigite was found after the first heavy rain, resulting from dissolved material from a clay bank which redeposited when the flow of water was retarded on more level ground and evaporation took place, due to hot weather immediately after the heavy showers. Myriads of glassy octahedral crystals on the clay and rocky soil and in the shallow creek bed presented a display of amazing brilliance in the bright sunlight. This mineral was also found along the south bank of Big Sulphur Creek. Small glassy octahedral crystals were seen in several small depressions in the hard rock. They were no doubt deposited after evaporation of water resulting from a recent shower. In other places here large crusts of crystallized tschermigite were collected and identified.

Alunogen in fine, fibrous, silky tufts occurs in many places in Geyser Creek Canyon as well as along the banks of a small creek flowing down a canyon below Lemonade Spring. The water in this creek is hot and contains much dissolved material, particularly aluminum sulphate, which gives it a strong astringent taste. Alunogen is also a prominent member of the sulphates at Sulphur Banks. Generally it is found as thick incrustations of rather striking appearance, with dark, almost black, or greenish rough surfaces and silky, fibrous interiors. The green crust usually reacts strongly for nickel.

Epsomite is commonly found near the upper and lower margin of the hot zone in Geyser Creek Canyon and in places along the south bank of Big Sulphur Creek. At a point where the trail enters Geyser Creek Canyon the west wall is composed of highly altered serpentine rock with many large cavities and pockets, resulting, no doubt, from the less resistant material being dissolved. The cavities are often coated with white powdery epsomite, which in places fills a considerable portion of the cavity. On the floor of two of the large cavities is a crust of epsomite 2 to 4 inches in thickness made up of compact fibres, light green in color. In other places here and near Lovers Leap, and on the east bank of Big Sulphur Creek, long white silky masses are common.

Halotrichite is not of common occurrence. At the base of quite a high bluff overhanging a small creek below the trail after it leaves the Devil's Pulpit a mineral thought to be halotrichite is quite abundant. Most of the material here is of a greenish-gray color and contains an appreciable amount of nickel. There is some doubt as to the identity of this nickeliferous mineral, the fibres at times being made up of short segments somewhat different from halotrichite. The normal yellowish-white silky halotrichite was found near Witches Cauldrons and sparingly at other places in Geyser Creek Canyon; it no doubt occurs also at Lemonade Springs section, although it was not observed there.

Alunite was first found in decomposed volcanics near Lemonade Spring in veins 1 to 3 inches in thickness, sometimes hard and porcelain-like with a smooth fracture. In veins of greater width nearby it is quite soft and resembles white clay. On drying, it becomes hard and pulverulent on the surface. Along the west bank of Geyser Creek for a considerable distance below Devil's Smoke Stack it is noticeable in many places and many veinlets of alunite were seen on the face of a bluff on the north bank of big Sulphur Creek a few hundred yards below The Geysers resort.

Voltaite in black crusts was found in Geyser Creek Canyon near Witches Cauldrons. The interiors of these crusts are crystalline. This mineral was also found at Sulphur Banks.

Melanterite is no doubt present in many places in Geyser Creek Canyon but only one or two specimens were picked up. No doubt some of the green iron sulphates seen in the canyon are melanterite; however, some boussingaultite has a structure similar to that of melanterite and, if colored green by nickel, could easily be mistaken for melanterite in the field.

A yellow iron sulphate containing a great deal of water can be seen in many places, but it was not identified.

Gypsum was observed at only one place in Geyser Creek Canyon, where it was found in an open fissure with opal, cinnabar, and a yellow iron sulphate. It occurs in long fibres, but very sparingly, and also in small crystals, poorly terminated. At Sulphur Bank it was found also in small, poorly developed crystals.

Pickeringite has been reported as occurring in Geyser Creek Canyon but none was found.[3]

One borate mineral was found near the entrance to Geyser Creek Canyon, near Arsenic Spring, but could not be identified. It is essentially a magnesium boro-sulphate and was first thought to be the mineral sulphoborite, but this was not proven. It is badly mixed with soda, lime, and ammonia, and forms as an efflorescent salt on the creek bank.

OTHER MINERALS AT "THE GEYSERS"

Sulphur is the most common mineral of The Geysers area. Near Lemonade Spring and at Sulphur Bank it is found in solid masses in great quantity. On the hot ground, hard, earthy looking crusts display countless brilliant sharply terminated crystals when overturned. Delicate crystals surround the vents of many small steam jets and line small fissures where vapors are constantly escaping. These latter occurrences are most common in Geyser Creek Canyon, where very little massive sulphur is found.

Pyrite in crystalline, brass-yellow smears can be found in many places in this canyon on lumps of black earth, if they are overturned. There is also much black iron sulphide in places.

Cinnabar was attached to mascagnite near Lemonade Spring and was also noticed in sulphur taken from another place nearby. The loose white decomposed siliceous earth and dark decomposed volcanics in this locality also contain some cinnabar. At Sulphur Banks it was also found. In Geyser Creek Canyon about 50 yards upstream from the Devil's Kitchen, on the south bank, cinnabar was found in decomposed and opalized rock. Here it is sparingly distributed in reddish smears and in the white earth in delicate pink shades.

Opal in delicate capillary fibres, sometimes branching out in radiated tufts resembling small cotton bolls, was found in small open fissures near the surface in Geyser Creek Canyon at the above-mentioned cinnabar occurrence. Sometimes it forms reticulated masses in the small depressions

[3] Allen, E. T., and Day, A. L., op. cit.

in the fissures, and again delicate, interlaced, loose fibres very much resembling mesolite of the finely fibrous type. Most of this fibrous material is pure white and is isotropic but some of the more glossy fibres are anisotropic and show extinction parallel to the length of the fibre. It was found that after treating the doubly refracting fibres with dilute hydrochloric acid, slightly warmed, and then drying, they become almost entirely isotropic. The solution, after removal of the fibres, was tested for sulphate and calcium and both were found to be present; which led to the conclusion that gypsum coated the fibres, making them appear anisotropic. The index of refraction is 1.45 and lower, index oil of 1.45 being the lowest available for the test. This fibrous material is insoluble in acids but is soluble in the strong alkalis. Analysis showed only silica and a trace of lime. On account of the very low index of refraction and because the material is isotropic, it is concluded to be opal. Projecting from the ceiling of the overhanging rock below Lovers Leap are many small hollow stalactites 2 to 5 inches long, from which water is constantly dripping, forming small flattened stalagmites below. These tubular stalactites are composed of silica, which is isotropic with low index of refraction and is probably opal. The flattened stalagmites are of similar material but contain many small lathlike crystals. These crystals appear to be triclinic with index refraction of 1.525. Their identity is not known. In many places a thick silica gel which is said to be opal is found in considerable quantity. In this material there is a trace of sulphate, ammonium, lime, magnesium, and aluminum.

Silicates are rather limited in number and can be found in the hills surrounding The Geysers. Most common of these is *tremolite* in fibrous aggregates and prismatic crystals. Tremolitic boulders are often encountered in creek bottoms and washes. *Pectolite* is generally, although sparingly, distributed throughout the area, most commonly filling small veins. Perhaps the most interesting silicate in the region is *stellerite*. It occurs in small tabular crystals, sharply developed, ranging in size from 2 to 4 millimeters. Sometimes it is in a calcite matrix and often in small open fissures with quartz and calcite. Stellerite was found in only two places, one at the base of the serpentine bluff about 200 yards north of the Devil's Pulpit, the other well up the ridge above the bluff. Small *actinolite* boulders were occasionally seen. The chrome-bearing kaolin, *miloschite,* is strikingly noticeable on account of its rather bright bluish-green color. Its most common occurrence is on the south slope near the top of the knob known as the Devil's Pulpit.

CONCLUSION

The minerals herein mentioned were identified by the usual methods of determination and were also examined under the microscope and the index of refraction, optical character, and other optical constants were determined wherever possible. The sulphate minerals, due to their fibrous nature and their more or less soft and hydrous character, do not lend themselves well to microscopic work; but enough of their optics was worked out, it is believed, to establish their identity. There are doubtful species, many of them, which appear to be mostly mixtures, although more work may show that some of these are distinct minerals. Some minerals found differ optically from related compounds given in the literature and are believed to be new species. These are being studied now by George

Switzer at Yale University and the results of his work will be published later.

In so large a thermal area as that which embraces all the patches of hot ground, all of which are more or less covered with sulphate salts, there can be little doubt that other minerals will be found. For those interested in these chemical products which Nature has so lavishly distributed in The Geysers area, there is a field rich in material for further research work.

Ammonia is prevalent everywhere in the region. Waters from the many hot springs and small streams are charged with ammonia and dissolved salts. Ammonia also contaminates most all of the sulphate minerals. This adds to the difficulty of identifying some of the material by the standard qualitative determinative methods, since ammonia may be present only as an impurity or it may be required in the constitution of the mineral. Material of this nature, if no satisfactory optical evidence could be found leading to its identity, was considered a mixture.

No acceptable theory has been advanced to explain the origin of the ammonia which is so abundantly present in the volcanic gases in The Geysers area. Its presence is doubtless more difficult to understand than that of the other gases. Only a trace of chlorine was found in some of the many samples of water tested and none of the salts contained more than a bare trace. In a place of dying volcanism such as The Geysers, more chlorine might be expected.

I wish to thank Dr. John Peoples, of Petaluma, for valuable assistance given on the many trips to The Geysers to collect material for study. His interest and willing aid is deeply appreciated.

SPECIAL ARTICLES

OBSERVATIONS AT "THE GEYSERS," SONOMA COUNTY, CALIFORNIA

By Walter W. Bradley*

Dr. Anderson [1] in the preface to his excellent book, the first comprehensive work on the mineral waters of California, states:

"Several years ago while visiting some of the prominent mineral springs and health resorts in this State the author satisfied himself that California possessed as valuable mineral springs as could be found anywhere in the world, and all that is needed to make them as serviceable in the restoration and maintenance of health as their famous sister springs in the East and in Europe is their further development, their chemical analysis, and the scientific administration and application of their waters. * * *"

"It will be observed by referring to the analytical tables that the California waters compare favorably with those of the European and Eastern States, in fact many of them are almost identical in composition."

As a result of observations and visits to the springs throughout California in his 34 years on the staff of the State Division of Mines, the author finds himself in agreement with Dr. Anderson's statement that California has a wealth of natural resources in her mineral waters and lacks only the systematic development and technical medical control in their utilization. In the present paper, however, we are dealing with a spot that has no superior elsewhere and that is unique in its specific qualities and characteristics.

Writing of a trip to The Geysers in 1862, an early-day San Francisco editor [2] says:

"Hot springs and cold springs; white, red, and black sulphur springs; iron, soda, and boiling alum springs; and the deuce only knows what other kind of springs, all pour their medicated waters into the little stream, until its once pure and limpid water—like a human patient made sick by over-doctoring—becomes pale and has a wheyish, sickly unnatural look as it feverishly tosses and tumbles over its rocky bed."

Though there are no true "geysers" (as the name "The Geysers" intimates), periodically spouting hot water into the air, there is an abundance of natural steam vents and a considerable number of hot springs. The locality is said to have been first brought to public attention in 1846 by a party of hunters; and local tradition credits its use by the Indians for its curative powers before the advent of the white man. A resort was early established, and "The Geysers" has been a name of world-renown for more than three-quarters of a century. It is 18 miles east of Cloverdale, by road, up Sulphur Creek; and may also be reached by roads from Healdsburg and Calistoga.

Because of the neighboring quicksilver districts the fumaroles and hot springs of The Geysers have been much described in their relation to the genesis of quicksilver ores, and there is a considerable bibliography thereon.[3]

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* State Mineralogist, California State Division of Mines. Manuscript submitted for publication July 24, 1946.

[1] Anderson, Winslow, Mineral springs and health resorts of California, with a complete chemical analysis of every important mineral water in the world, 384 pp., illus., San Francisco, 1890.

[2] Hutchings, J. M., Scenes of wonder and curiosity in California, 3d ed., p. 232, 1870.

[3] Bradley, W. W., Sonoma County: California Min. Bur. Rept. 14, p. 340, 1916.

In February 1922, the author,[4] with a rather crude arrangement of apparatus, obtained positive reactions for radioactivity at The Geysers on gases in the natural steam issuing from crevices in the north-side wall of the canyon of Sulphur Creek at a point where the bank had been excavated and then covered by two rooms with concrete walls to be utilized for steam baths.

These tests were followed in August of the same year by a series of qualitative tests made by the writer and Mr. Frank Sanborn, determinative mineralogist of the State Mining Bureau staff. In the interim, Mr. J. D. Grant, owner, had drilled two wells in the fumarole area to investigate the possibilities of this natural steam supply as a source of power convertible into electricity. Grant, however, was not the first one to think of this steam in terms of power. Cronise,[5] in 1868 describes the ''Steamboat'' fumarole as:

"* * * about two feet in diameter, through which is constantly ejected, with the noise of a number of steamers, a body of steam sufficient, could it be controlled, to propel a large amount of machinery. This steam is so hot as to be invisible for five or six feet above the aperture through which it issues. On a clear day it arises in a column to a height of more than three hundred feet."

The second well (later designated No. 1, as the first one had collapsed) was at a depth of 181 feet 6 inches (later drilled to 203 feet). With the top valve closed (12-inch casing) and the valve in an 8-inch horizontal pipe wide open, the steam gauge showed a pressure of 60 pounds per square inch; and a Brown expansion pyrometer indicated a temperature of 530° F. Gas for testing was led off through a $\frac{3}{4}$-inch pipe tapped into the side of the well pipe. It was condensed, cooled, dehydrated, and the dry gas passed through a gold-leaf electroscope. Positive and strong reactions for radium emanations were repeatedly obtained.

Well-drilling operations continued in a more ambitious program up to the fall of 1925 [6] under the corporate organization of the Geyser Development Company. In all, eight wells were drilled, the deepest being 650 feet. Analyses of the steam and accompanying gases quoted through the courtesy of Mr. J. D. Galloway, consulting engineer for the company, show for wells Nos. 1, 2, 4, and 5 averages of: Noncondensible gases 1.02%; soluble gases 0.027%; steam (by difference) 98.95%. Of the noncondensible gases, the averages were: 67.32% CO_2, 12.92% H, 11.68% methane (CH_4), 2.72% H_2S; of the soluble gases, 15.0% NH_3, 3.9% H_2S, 15.05% CO_2.

In 1924-26, Allen and Day [7] of the Carnegie Institute of Washington, conducted a study of this natural steam and its activity. Their conclusions confirm the theory that its source is deep-seated; that it is of magmatic origin, and its channel of escape to the surface is along a fault which courses northwestward along the southern side of a ridge of the Mount St. Helena range. A summary of their analyses of the volcanic gases is given in the table on page 297.

[4] Bradley, W. W., Radioactivity in thermal gases at The Geysers, Sonoma County, California: California Min. Bur. Rept. 18, pp. 545-550, 1922.

[5] Cronise, T. F., The natural wealth of California, p. 173, 1868.

[6] Laizure, C. McK, Sonoma County: California Min. Bur. Rept. 22, pp. 343-353, 1926.

[7] Allen, E. T., and Day, A. L., Steam wells and other thermal activity at "The Geysers," California: Carnegie Inst. Washington Pub. 378, 106 pp., 34 figs., 1927.

FUMAROLE AREA IN UPPER GEYSER CREEK,
SONOMA COUNTY

A, THE STEAM "CAVES" AT THE GEYSERS, SONOMA COUNTY
On a cold morning in 1938.

B, THE STEAM "CAVES" AT THE GEYSERS, SONOMA COUNTY
On a hot summer day in 1939. This picture shows the new concrete cubicles built over the steam vents. Note difference in steam display.

"*Table 13—Complete analyses of several volcanic gases from The Geysers, California. Computed* from the data in tables 9 and 12.*

Place	H_2O	CO_2	H_2	CH_4	$N_2 + A$	H_2S	NH_3	*Sum*
Well 1	98.045	1.242	0.287	0.299	0.069	0.033	0.025	100.000
Well 2	98.686	.777	.216	.208	.048	.042	.023	100.000
Well 5	98.869	.716	.160	.167	.035	.035	.018	100.000
Well 6	98.946	.661	.148	.156	.034	.037	.018	100.000
Steamboat Fumarole	99.202	.520	.098	.110	.022	.029	.019	100.000

* These figures are given to thousandths of a per cent regardless of experimental error in the principal constituents, the better to express the relationship to the lower constituents."

Temperature readings taken by Day [8] with valves open were recorded as follows:

Well No. 2 165.6° C. at top; 168.6° C. at 320 ft. depth, bottom
Well No. 4 163.4° C. at top; 172.6° C. at 451 ft. depth, bottom
Well No. 8 150° C. at top; 157.2° C. at 636 ft. depth, bottom

Tests were made in Well No. 5 closed, by lowering pieces of test metals with melting points of 600° F. (315° C.), 500° F. (270° C.), and 450° F. (232° C.). These were lowered to a depth of 250 feet and held 15 minutes. Only one metal, that melting at 232° C., was completely melted. In a second test the metals were lowered to the bottom, 416 feet, with a similar result.

Temperatures recorded by the author in August 1938 in the steam rooms were: "Steam Cave No. 1," 110° F. at 2 feet above the floor; 120° F. at 4 feet; 130° F. at 6 feet above the floor. "Steam Cave No. 2," 98° F. to 104° F. in the center of room. In both rooms the temperature of the live steam in the orifices of the vents where it issues from the bank is 200° F. The reason for the lower readings in No. 2 is that there are only two small orifices there as against several larger ones in No. 1. Patients "cool off" in No. 2 after treatment in No. 1.

In the Geyser Canyon on June 26, 1938, temperatures of 180° F. to 200° F. were obtained in several of the pools depending on nearness of the thermometer to the steam vents which heat the pools. In the open steam vents not covered by surface water at the time, readings of 200° F. to 204° F. were obtained. These temperatures agreed with readings taken by the author at the same locations in October 1913.[9] The author was led to make the qualitative tests for radioactivity referred to herein as a result of the work of Schlundt and Moore [10] in Yellowstone National Park. Their tests showed that so far as the radioactivity was concerned, neither the temperature of the waters or gases, nor the acidity or alkalinity were significant. Some of the hot springs showed no radium emanation, and some of the cold springs gave strong reactions.

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88 Eighth annual report of the State Mineralogist for the year ending October 1, 1888: California Min. Bur. Rept. 8, 948 pp. (The Geysers, p. 635), illus., 1888.

Laizure, C. McK.

26 Sonoma County: California Min. Bur. Rept. 22, pp. 327-365 (The Geysers, pp. 343-353), illus., 1926.

Peale, A. C.

86 Lists and analyses of the mineral springs of the United States (a preliminary study): U. S. Geol. Survey Bull. 32, 235 pp. (The Geysers, pp. 204, 206), 1886.

Schlundt, Herman

09 (and Moore, R. B.) Radioactivity of the thermal waters of Yellowstone National Park: U. S. Geol. Survey Bull. 395, 35 pp., 4 pls., 1909.

Waring, Gerald A.

15 Springs of California: U. S. Geol. Survey Water-Supply Paper 338, 410 pp. (The Geysers, pp. 83-88), 13 pls., 1915.

Whitney, Josiah Dwight

65 Geological survey of California; geology vol. 1; report of progress and synopsis of the field work from 1860 to 1864, xxvii, 498 pp. (The Geysers, pp. 93 et seq.), 1865.

MINERAL EXHIBIT AND STATISTICS

ACCESSIONS TO THE EXHIBIT

BY HENRY H. SYMONS*

The museum of the State Division of Mines possesses an exceptionally fine collection of rocks and minerals of economic and academic value. It ranks among the first five such collections in North America and contains not only specimens of most of the known minerals found in California, but much valuable and interesting material from other States and foreign countries as well.

The exhibit is daily visited by service men, engineers, students, business men, and prospectors as well as tourists and sightseers. In addition to its practical use in the economic development of California's mineral resources, the collection is a most valuable educational asset to the State and to San Francisco.

Mineral specimens suitable for exhibit purposes are solicited, and their donation will be appreciated by the Division of Mines, as well as by those who utilize the facilities of the collection.

Among the specimens received recently and catalogued for the exhibit are the following:

21226 CHRYSOTILE, the asbestos variety of serpentine, from old Regal mine, Gila County, Arizona, now operated by the Arizona Chrysotile Company. Donor: Samuel A. Abrahams, May 1946. Case 402.

21227 QUARTZ, SiO_2, an unusual occurrence of crystals forming radial spherulites, colored with iron oxides giving it the appearance of jasper. From Alexander Valley, Sonoma County, California. Donor, Wilhelm Haedler, May 1946. Case 114.

21228 High-grade SILVER ore, chiefly PYRARGYRITE, $3Ag_2S.Sb_2S_3$, and PROUSTITE, $3Ag_2S.As_2S_3$, associated with galena and sphalerite. From Smuggler mine, Silver Plume, Colorado. Donor: George L. Gary, May 1946. Case 310.

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* Statistician and Curator, California State Division of Mines.

STATISTICS

By Henry H. Symons*

At present (May 1946), reports from most of the 1945 producers have been received. Data for several substances are now compiled, and are presented herein.

BORATES

During the year, there was produced in California a total of 314,415 net tons of borate material, as compared with 276,398 tons for the preceding year. The material shipped during the year included the sodium borates, kernite (rasorite), kramerite from Kern County; also crystallized borax prepared by evaporation of brines at Searles Lake in San Bernardino County and Owens Lake in Inyo County, and a small amount of colemanite from Death Valley, Inyo County.

As the crude ore is not sold as such but is almost entirely refined into borax of commerce before shipping, and because of the fact that the material varied widely in boric acid content, we have recalculated the tonnage to a basis of 40 percent A. B. A. This is approximately the average A. B. A. content of colemanite material after calcining, and also of the crystallized borax obtained from evaporation of the lake brines.

Recalculated, the 1945 output totaled 257,299 net tons, valued at $5,898,823, as compared with 234,860 tons worth $5,264,864 for the year 1944. The above came from two properties each in Inyo and San Bernardino Counties, and one in Kern County.

GYPSUM

Shipments of gypsum in California during 1945 amounted to a total of 442,133 net tons worth $954,696 and came from two properties each in Imperial and Kern Counties; and one property each in Monterey, Riverside, and Ventura Counties. The 1945 output showed an increased value with a decrease in amount as compared with that of 1944. This was accounted for by a larger percentage of high grade gypsum compared with gypsite and the fact that most producers of gypsum reported a higher unit value. The 1944 totals were 558,488 tons valued at $949,833. In addition to the above figures a considerable amount of gypsum came from Alameda County, which was obtained in a chemical process for reducing magnesium salts from salt-works bittern water with lime, the amount of which was not included in the above figures as it was used with limestone and magnesia. The 1945 value is the largest of any annual output so far reported. The gypsum mined in the State is used in the manufacture of hard-wall and other plasters, wallboard, in cement, and for agricultural purposes. The increase in recent years in the uses of this material is chiefly in the agricultural field, the tonnage for which now exceeds that for industrial and structural plasters, and that used in cement.

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* Statistician and Curator, State Division of Mines.

IRON ORE

The iron ore shipped from California properties, during 1945 totaled 240,917 net tons, valued at $883,434 f.o.b. mine, and came from one property each in Riverside, San Bernardino, Santa Cruz, and Shasta Counties. The above figures showed a decrease in amount and value as compared with the 1944 output of 905,981 net tons, worth $2,360,694.

The ore mined during the year was hematite from Riverside and San Bernardino Counties which went to the steel plant at Fontana and was also used in the manufacture of high-iron cement; and as foundry flux; magnetite from Shasta County and magnetite sands from Santa Cruz County, both used as an aggregate in heavy concrete for ballast.

LIMESTONE

'Industrial' limestone was shipped from 22 properties in 14 counties during 1945 and totaled 532,480 net tons, valued at $1,626,844, as compared with 734,425 tons, worth $1,714,414, in 1944 which came from 18 properties in 10 counties. Distribution of the 1945 output by counties was as follows:

County	*Amount*	*Value*
San Bernardino	121,183	$285,827
Santa Clara[a]	45,274	138,122
Alameda,[a] Amador, El Dorado, Inyo, Riverside, San Luis Obispo, San Mateo,[a] Santa Cruz, Shasta, Siskiyou, Tuolumne, Ventura*	366,023	1,202,895
Totals	532,480	$1,626,844

[a] Includes shells dredged from San Francisco Bay.
* Combined to conceal the output of operators in each.

Included in the above figures are 183,643 tons of limestone used in making 91,825 net tons of lime, valued at $997,236, which came from two properties in San Bernardino County and one each in Alameda, El Dorado, Santa Cruz, and Tuolumne Counties. The figures for lime do not include lime burnt from dolomite and used in the reduction of magnesia from sea water. Dolomite is treated as a separate mineral substance. In 1944 there were 164,494 tons of limestone burnt to make 82,247 net tons of lime, valued at $883,009. Also included were 83,856 tons of limestone, valued at $503,817, which was used for agricultural purposes and poultry grit, stock feed and as a filler in fertilizers.

QUICKSILVER

Quicksilver produced in California during 1945 came from 43 properties in 12 counties and amounted to a total of 21,063 flasks (76 pounds), valued at $2,697,835 f.o.b. mine. This was a decrease in both amount and value as compared with the 1944 output which was 28,097 flasks, worth $3,178,969 f.o.b. mine, and came from 63 properties in 14 counties.

A breakdown of the 1945 production by counties was not given as it would essentially reveal the output of the principal producer in the individual county. The New Idria mine in San Benito County continued to be the largest producer, followed in turn by the Mount Jackson mine in Sonoma County; the Reed mine in Yolo County and the Abbott mine in Lake County. Other counties having producing properties were Contra Costa, Del Norte, Fresno, Kings, Napa, San Luis Obispo, Santa Clara, and Trinity.

California as in the past led all other states in the United States with approximately 70 percent of the nation's yield. Quotations at New York for quicksilver started the year 1945 with an average of $156.85 per flask (76 pounds) for January, going to a high of an average of $165.55 per flask for February; then dropping to a low of an average of $95.84 per flask for September and ending the year with an average of $108.00 per flask for December. The average of New York quotations for the year was $134.89 per 76-pound flask compared with $118.36 per flask in 1944; and $195.21 per flask in 1943. The California miner received an average of $128.08 per 76-pound flask for his quicksilver in 1945; compared with $113.14 per flask in 1944; and $181.96 per flask in 1943.

SALT

Most of the salt production in California is obtained by evaporation of water of the Pacific Ocean, plants being located on the shores of San Francisco, Monterey, and San Diego Bays, and at Long Beach. Additional amounts are derived from lakes and lake beds in the desert regions (in part, rock salt), mainly in Imperial, Kern, and San Bernardino Counties, and evaporation of alkaline lake water in Modoc County. A small amount of valuable medicinal salts has been obtained by evaporation of the water of Lake Mono, Mono County, and from a mineral spring in Butte County.

The 1945 salt production in California totaled 734,736 net tons, valued at $2,030,226, and came from three properties in Alameda County; two in San Bernardino County; and one each in Kern, Los Angeles, Mono, Monterey, Orange, and San Diego counties. The 1944 salt output was the largest annual yield ever reported in this State and was 769,873 tons worth $2,060,960. The average value reported by salt producers in California in 1945 was $2.76 per net ton, f.o.b. plant compared with $2.68 in 1944; $2.68 in 1943; $2.90 in 1942; $2.72 in 1941; $2.79 in 1940; $2.75 in 1939; and $2.78 in 1938.

SODA

The production of sodium salts in California in 1945 included soda ash, and trona, from plants at Owens Lake, Inyo County; and soda ash, salt cake, and trona (sequi-carbonate, a double salt of Na_2CO_3 and $NaHCO_3$) from Searles Lake, San Bernardino County. The plant on Dale Lake near Amboy and Searles Lake, San Bernardino County, started operations during the year 1940 and made shipments of salt cake in 1941. There were no shipments of salt cake (sulphate) from Carrizo Plains, San Luis Obispo County. Shipments made during the year 1945 totaled 311,236 net tons valued at $3,793,571 as compared with 299,574 tons worth $3,647,630 in 1944. The 1945 output had the largest amount and value of any annual production ever reported in this State. In 1945 193,785 tons of soda ash and 117,451 tons of salt cake were reported shipped in California.

The soda ash was used mainly in the manufacture of soap, glass, paper, oil refining, sugar refining, chemicals, and water softener; and the trona for metallurgical purposes, as in the refining of copper, tungsten, and aluminum; in chemicals and water purification. The salt cake or sodium sulphate was used in the manufacture of paper, glass, and in chemicals.

LIBRARY

LIBRARY REPORT

By James M. Little *

OUTLINE OF REPORT

INTRODUCTION

The library of the Division of Mines contains more than 6,000 selected volumes on mines, mining, and allied subjects. It is also the repository for reports and bulletins of technical departments of Federal and State governments and educational institutions both domestic and foreign. Current copies of newspapers published in the mining centers of the State are also available for reference.

The library and reading room are open to the public during the usual office hours, when the librarian may be freely called upon for all necessary assistance.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY AND UNITED STATES BUREAU OF MINES

The library of the Division of Mines has available for public reference the following publications of the United States Geological Survey: Annual Reports, Monographs, Professional Papers, Bulletins, Water-Supply Papers, Mineral Resources, Folios of the Geologic Atlas of the United States (broken file), Maps with Descriptive Text (broken file), Administrative Publications (broken file); and the following publications of the United States Bureau of Mines: Bulletins, Technical Papers, Economic Papers (broken file), Mineral Resources of the United States, Monographs (broken file), Reports of Investigations, Information Circulars.

* Librarian, California State Division of Mines.

PUBLICATIONS OF STATE SURVEYS

A broken file of mining and geological publications, issued by the organizations listed below, may be consulted in the library of the Division of Mines.

Alabama Geological Survey, University.
Alaska (Territorial Commissioner of Mines), Juneau.
Arizona Bureau of Mines, Tucson.
Arkansas Geological Survey, Little Rock.
Colorado Bureau of Mines, Denver.
Connecticut Geological and Natural History Survey, Hartford.
Florida Department of Conservation, Tallahassee.
Georgia Division of Geology, Atlanta.
Idaho Bureau of Mines and Geology, Moscow.
Illinois Geological Survey, Urbana.
Indiana Division of Geology, Indianapolis.
Iowa Geological Survey, Des Moines.
State Geological Survey of Kansas, Lawrence.
Kentucky Geological Survey, Frankfort.
Louisiana Department of Conservation, New Orleans.
Maine State Geologist, Augusta.
Maryland Geological Survey, Baltimore.
Michigan Geological Survey, Lansing.
Minnesota Geological Survey, Minneapolis.
Mississippi State Geological Survey, University.
Missouri Bureau of Geology and Mines, Rolla.
Montana Bureau of Mines and Geology, Butte.
Nebraska Geological Survey, Lincoln.
Nevada State Bureau of Mines, Reno.
New Jersey Department of Conservation and Development, Trenton.
New Mexico Bureau of Mines and Mineral Resources, Socorro.
New York Science Division, Albany.
North Carolina Geological and Economic Survey, Chapel Hill.
North Dakota Geological Survey, Grand Forks.
Ohio Geological Survey, Columbus.
Oklahoma Geological Survey, Norman.
Oregon State Department of Geology and Mineral Industries, Portland.
Pennsylvania Topographic and Geological Survey, Harrisburg.
South Dakota State Geological Survey, Vermillion.
Tennessee Division of Geology, Nashville.
Texas Bureau of Economic Geology, Austin.
Virginia Geological Survey, University.
Washington State Department of Conservation and Development, Pullman.
West Virginia Geological Survey, Morgantown.
Wisconsin Geological and Natural History Survey, Madison.
Wyoming Geological Survey, Cheyenne.

PUBLICATIONS OF FOREIGN GOVERNMENTS

Publications of the following foreign governments are received and current issues may be consulted in the library. Earlier issues of foreign-language publications have been loaned to the California Academy of Sciences in Golden Gate Park, because of the limited storage space at the Division's offices in the Ferry Building. They may, however, be consulted at the Academy.

Alberta Research Council, Edmonton.
Argentina Direccion General de Minas y Geologica, Buenos Aires.
Brazil, Divisao de Geologica e Mineralogie, Rio de Janerio.
Brazil, Ministry de Foreign Affairs, Rio de Janerio.
British Columbia Minister of Mines, Victoria.
British Museum of Natural History, London.
Canada Department of Mines, Ottawa.
Cuerpo de Ingenieros de Minas del Peru, Lima.
Department of Scientific and Industrial Research, Wellington, N. Z.
Federated Malay States, Geological Survey, Kuala Lumpur.
Geological Service of Minas Geraes, Bella Harizonte, Brazil.
Geological Survey of Scotland.
Geological Survey, West Australia, Perth.
Gouvernment General de L'Afrique Equatoriale Francaise, Service des Mines, Brazzaville.
Gouvernment General de L'Afrique Occidentale Francaise, Service des Mines, Dakar.
Instituto Historica e Geographico, Rio de Janerio.
Mexico, Universidad Nacional Autonoma de Mexico, Mexico, D. F.
Ministerio da Agricultura, Divisao de Geologia e Mineralogia, Rio de Janerio.

Ministerio de Agricultura, Direccion de Minas y Geologia, Buenos Aires, Argentina.
Ministerio de Fomento y Obras Publicas, Lima, Peru.
Museo de Historia Natural de Montevideo, Uruguay.
Museu Nacional, Rio de Janerio, Brazil.
New South Wales, Department of Mines, Sydney.
New Zealand Geological Survey Branch, Wellington.
Nova Scotia Department of Public Works and Mines, Halifax.
Ontario Department of Mines, Toronto, Canada.
Quebec, Bureau of Mines, Quebec.
Queensland Department of Mines, Brisbane, Australia.
Queensland Government Mining Journal, Brisbane.
Republica Argentina, Direccion de Minas, Geologia e Hidrogeologia, Buenos Aires.
Royal Society of South Australia, Department of Mines, Adelaide.
Secretaria de la Economia Nacional, Direccion General de Minas y Petroleo, Mexico, D. F.
South Australia Department of Mines, Adelaide.
Universidad Nacional de Tucuman, Tucuman, Argentina.
Victoria, Department of Mines, Melbourne, Australia.
Western Australia Geological Survey, Perth.

PUBLICATIONS OF DOMESTIC SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academy of Natural Sciences of Philadelphia.
American Association of Petroleum Geologists, Tulsa, Oklahoma.
American Geographical Society of New York.
American Institute of Mining and Metallurgical Engineers, New York.
American Journal of Science, New Haven, Conn.
California Academy of Sciences, San Francisco.
Carnegie Institution of Washington.
Cleveland Museum of Natural History, Cleveland, Ohio.
Colorado College, Colorado Springs, Col.
Colorado School of Mines, Golden, Col.
Colorado Scientific Society, Denver.
Commonwealth Club, San Francisco.
Economic Geology, Lancaster, Pa.
Field Museum of Natural History, Chicago.
Franklin Institute, Lancaster, Pa.
Geological Society of America, Baltimore.
Journal of Geology, Chicago.
Journal of Paleontology, Chicago.
Mineralogical Society of America, Menasha, Wis.
Michigan College of Mining and Technology, Houghton.
Mining and Metallurgical Society of America, New York.
Missouri School of Mines and Metallurgy, Rolla.
National Research Council, Washington, D. C.
National Speleological Society, Washington, D. C.
New York Academy of Sciences, New York.
New York State Museum, Albany.
Pennsylvania State College, State College.
San Diego Society of Natural History, San Diego, California.
Santa Barbara Museum of Natural History, Santa Barbara, California.
Seismological Society of America, Stanford University.
Sierra Club, San Francisco.
Southern California Academy of Sciences, Los Angeles.
Stanford University, California.
University of California Publications in Engineering, Geography and Geology, Berkeley.
University of Harvard, Department of Mineralogy and Petrography, Cambridge, Mass.

PUBLICATIONS OF FOREIGN SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academia de Ciencias y Artes de Barcelona, Spain.
Australian Museum, Sydney.
Canadian Institute of Mining and Metallurgy, Montreal.
Chamber of Mines of West Australia, Kalgoorlie.
Geological Society of London.
Institution of Mining and Metallurgy, London.
Instituto Geologica de Mexico, Mexico, D. F.
Journal of the Royal College of Science, London.
Mexico Journal, Compilation and Translation Department, San Antonio, Texas.
Philippine Journal of Science, Manila.
Royal Society of South Australia, Adelaide.
Transvaal Chamber of Mines, Johannesburg.

CURRENT MAGAZINES

Current issues of the technical magazines listed below are on file in the reading room of the library, and may be consulted.

ADT Transmitter, New York.
Asbestos, Philadelphia.
Bakelite Review, New York.
Brick and Clay Record, Chicago.
California Highways and Public Works, Sacramento.
California Magazine of the Pacific, San Francisco.
California Mining Journal, Auburn.
California Oil World, Los Angeles.
California Safety News, San Francisco.
Canadian Mining Journal, Gardenvale, Quebec.
Chemical and Metallurgical Engineering, New York.
Chemical Industries, Philadelphia.
Deco Trefoil, Denver.
Desert Magazine, El Centro.
Du Pont Magazine, Wilmington, Del.
Driller, South Milwaukee,
Engineering and Mining Journal, New York.
Fairbanks-Morse News, Chicago.
Foote Prints, Philadelphia.
Fusion Facts, Whittier.
Gemmologist, London.
Grizzly Bear, Los Angeles.
Hercules Mixer, Wilmington, Del.
Highway Magazine, Middletown, Ohio.
Highway Traveler, Cleveland.
Independent Monthly, Tulsa, Oklahoma.
Johnson National Distillers Journal, St. Paul.
Light, Cleveland.
Light Metal Age, Chicago.
Lubrication, New York.
Marion Groundhog, Marion, Ohio.
Metals and Alloys, Pittsburgh, Pa.
Mineralogist, Portland, Ore.
Mines Magazine, Denver.
Mining and Contracting Review, Salt Lake City.
Mining and Geological Journal, Melbourne, Victoria, Australia.
Mining and Industrial News, San Francisco.
Mining and Metallurgy, New York.
Mining Congress Journal, Washington, D. C.
Mining Journal, Phoenix, Arizona.
Mining Journal, London.
Mining World, Seattle.
Nickel Steel Topics, New York.
Oil and Gas Journal, Tulsa, Oklahoma.
Oil, Paint and Drug Reporter, New York.
Oil Weekly, Houston, Texas.
Pacific Road Builder, San Francisco.
Pacific Purchaser, San Francisco.
Pay Dirt, Phoenix, Arizona.
Petroleum World, Los Angeles.
Pit and Quarry, Chicago.
Rock Products, Chicago.
Rocks and Minerals, Peekskill, N. Y.
Scientific American, New York.
Silicate, P's & Q's, Berkeley.
Standard Oil Bulletin, San Francisco.
Storage Battery Power, West Orange, N. J.

NEWSPAPERS

Current issues of the following papers are received and kept on file in the library:

Alaska Weekly, Seattle, Washington.
Amador Dispatch, Jackson, California.
Banner, Sonora, California.
Barstow Printer, Barstow, California.
Bridgeport Chronicle-Union, Bridgeport, California.
Calaveras Californian, Angels Camp, California.
Calaveras Prospect, San Andreas, California.
Daily Commercial News, San Francisco, California.
Del Norte Triplicate, Crescent City, California.
Denver Mining Record, Denver, Colorado.
Inyo Independent, Independence, California.
Inyo Register, Bishop, California.

Las Vegas Age, Las Vegas, Nevada.
Livermore Herald, Livermore, California.
Los Angeles Times, Los Angeles, California.
Mariposa Gazette, Mariposa, California.
Mining Press, Reno, Nevada.
Mohave Miner, Kingman, Arizona.
Morning Union, Grass Valley, California.
Mountain Messenger, Downieville, California.
Needles Nugget, Needles, California.
Oroville Mercury Register, Oroville, California.
Placer Herald, Auburn, California.
Placerville Times, Placerville, California.
Plumas Independent, Quincy, California.
Randsburg Times, Randsburg, California.
Tehachapi News, Tehachapi, California.
Terra Bella News, Terra Bella, California.
Tuolumne Independent, Sonora, California.
Tuolumne Prospector, Tuolumne, California.
Union Democrat, Sonora, California.
Weekly Trinity Journal, Weaverville, California.
Yreka Journal, Yreka, California.

NEW BOOKS

Recent accessions to the library are the following books:

Fanning, L. M., Our Oil Resources, 331 pp., New York, McGraw-Hill Book Co., 1945. (Donated by John R. Callaham).

Jones, P. J., Petroleum Production, Vol. 1, 228 pp., New York, Reinhold Publishing Co., 1946. (Donated by John R. Callaham).

Liddell, D. M. and others, Handbook of Nonferrous Metallurgy, Vol. 1, Principles and Processes, 2nd Ed., 656 pp., New York, McGraw-Hill Book Co., 1945.

Nonferrous Metallurgy, Vol. 2, Recovery of the Metals, 2nd Ed., 721 pp., New York, McGraw-Hill Book Co., 1945. (F. W. Bradley Memorial Book Fund).

Rhodes, F. H., Technical Report Writing, 125 pp., New York, McGraw-Hill Book Co., 1941. (Donated by John R. Callaham).

Smith, C. V. and others, 6 reprints from "Asbestos", Philadelphia, Asbestos. (F. W. Bradley Memorial Book Fund).

Stokley, J., Electrons in Action, 227 pp., New York, Whittlesey House 1946. (F. W. Bradley Memorial Book Fund).

Strack, L. H., Asbestos, a Magic Mineral, 56 pp., New York, Harper & Bros., 1941. (F. W. Bradley Memorial Book Fund).

Tarr, W. A., Introductory Economic Geology, 2nd Edition, 645 pp., New York, McGraw-Hill Book Co., 1938.

SERVICES OF THE DIVISION OF MINES

The Division of Mines (formerly State Mining Bureau) is maintained for the purpose of assisting in all possible ways in the development of California's mineral resources.

As one means of offering tangible service to the mining public, the State Mineralogist for many years has issued an annual or a biennial report reviewing in detail the mines and mineral deposits of the various counties.

As a progressive step in advancing the interests of the mineral industry, and as permitting earlier distribution to the public, publication of the Annual Report of the State Mineralogist in the form of monthly chapters was begun in January 1922, and continued until March 1923. Owing to a lack of funds for printing this was changed to a quarterly publication, beginning in September 1923. For the same reason, beginning with the January 1924 issue, it became necessary to charge a subscription price. This covers approximately the cost of printing.

Pages are numbered consecutively throughout the year and an index to the complete report is included annually in the closing number.

Beginning with the 1930 issues, the activities and progress of the Geologic Branch are recorded also in these quarterly chapters. The important part that geology plays in the economic development of our mineral resources is further recognized in the change of title from *Mining in California* to CALIFORNIA JOURNAL OF MINES AND GEOLOGY, beginning with the January 1933 chapter.

While current activities of all descriptions are covered in these chapters, the practice of issuing from time to time technical reports on special subjects will be continued as well. A list of such reports now available is appended hereto, and the names of new bulletins will be added in the future as they are completed.

The chapters are subject to revision, correction and improvement. Constructive suggestions from the mining public will be gladly received, and are invited.

The one aim of the Division of Mines is to increase its usefulness and to stimulate the intelligent development of the wonderful, latent resources of the State of California.

TYPES OF REPORTS

In general the reports presented in these chapters are grouped into three classes:

1. Mines and mineral resources of a given county or area (describing kind, character, distribution and extent of development).

2. Specific economic and industrial mineral products (listing and describing the resources over the entire State of a given mineral substance, e.g., feldspar).

3. Geological reports on specific areas (recording results and conclusions with maps, derived from field studies; and tied in with economic possibilities and developments).

Reports of District Mining Engineers

In 1919-1920 the Mining Bureau was organized into four main geographical divisions, with the field work delegated to a mining engineer in each district, working out from field offices that were established in Redding, Auburn, San Francisco and Los Angeles, respectively. This move brought the office into closer personal contact with operators, and it has many advantages over former methods of conducting field work, including lower traveling-expense bills for the Bureau's engineers. In 1923 the Redding and Auburn field offices were consolidated and moved to Sacramento.

The Redding office was reestablished in 1928, and the boundaries of each district adjusted. The counties now included in each of the four divisions and the locations of the branch offices are shown on the frontispiece outline map of the State.

Reports of mining activities and development in each district, prepared by the District Engineer, will continue to appear under the proper field division heading.

Special Articles

Detailed technical reports on special subjects, the result of research work or extended field investigations, will continue to be issued as separate bulletins by the Division, as has been the custom in the past.

Shorter and less elaborate technical papers and articles by members of the staff and others are published in each number of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

These special articles cover a wide range of subjects both of historical and current interest; descriptions of new processes, or metallurgical and industrial plants, new mineral occurrences, and interesting geological formations, as well as articles intended to supply practical and timely information on the problems of the prospector and miner, such as the text of new laws and official regulations and notices affecting the mineral industry.

MAIL AND FILES

The Division of Mines maintains, in addition to its correspondence files and the library, a mine file which includes original reports on the various mines and mineral properties of all kinds in California.

During each quarterly period there are several thousand letters received and answered at the San Francisco office alone, covering almost every phase of prospecting, mining and developing mineral deposits, reduction problems, marketing of refined products and mining law. In addition to this, hundreds of oral questions are answered daily, both at the main office and the district offices, for the many inquirers who come in for personal interviews and to consult the files and library.

The library has a card-file system for references to individual California mines, occurring in the publications of the Division of Mines, in the Mining and Scientific Press, the Engineering and Mining Journal, and the Arizona Mining Journal.

COMMERCIAL MINERAL NOTES

The producer and consumer of mineral products are mutually dependent upon each other for their prosperity, and one of the most direct aids rendered by this Division to the mining industry in the past

has been that of bringing producers and consumers into direct touch with each other.

This work has been carried on largely by correspondence, supplemented by personal consultation. Lists of buyers of all the commercial minerals produced in California have been made available to producers upon request, and likewise the owners of undeveloped deposits of various minerals, and producers of them, have been made known to those looking for raw mineral products.

When the publication of *Mining in California* was on a monthly basis, current inquiries from buyers and sellers were summarized and lists of mineral products or deposits 'wanted' or 'for sale' included in each issue.

It is important that inquiries of this nature reach the mining public as soon as possible and in order to avoid the delay incident to the present quarterly publication of CALIFORNIA JOURNAL OF MINES AND GEOLOGY, these lists are now issued monthly in the form of a mimeographed sheet under the title of *Commercial Mineral Notes,* and sent to those on the mailing list of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

EMPLOYMENT SERVICE

Following the establishment of the Mining Division branch offices in 1919, a free technical employment service was offered as a mutual aid to mine operators and technical men for the general benefit of the mineral industry.

Briefly summarized, men desiring positions are registered, the cards containing an outline of the applicant's qualifications, position wanted, salary desired, etc., and as notices of 'positions open' are received, the names and addresses of all applicants deemed qualified are sent to the prospective employer for direct negotiations.

Telephone and telegraphic communications are also given immediate attention.

Technical men, or those qualified for supervisory positions, and vacancies of like nature only, are registered, as no attempt will be made to supply mine and mill labor.

Registration cards for the use of both prospective employers and employees may be obtained upon request, and a cordial invitation is extended to the industry to make free use of the facilities afforded. Parties interested should communicate direct with our San Francisco office.

DETERMINATION OF MINERAL SAMPLES

Samples (limited to two in one month) of any mineral found in the State may be sent to the Division of Mines for identification, and the same will be classified free of charge. No samples will be determined if received from points outside the State. It must be understood that no assays, or quantitative determinations will be made. Samples should be in lump form if possible, and marked plainly with name of sender on outside of package, etc. No samples will be received unless delivery charges are prepaid. A letter should accompany sample, giving locality where mineral was found and the nature of the information desired.

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During the past sixty-five years, in carrying out the provisions of the organic act creating the former California State Mining Bureau, there have been published many reports, bulletins and maps which go to make up a library of detailed information on the mineral industry of the State, a large part of which could not be duplicated from any other source.

One feature that has added to the popularity of the publications is that many of them have been distributed without cost to the public, and even the more elaborate ones have been sold at a price which barely covers the cost of printing.

Owing to the fact that funds for the advancing of the work of this department have usually been limited, the reports and bulletins mentioned are printed in limited editions many of which are now entirely exhausted.

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**Report II of the State Mineralogist, 1882, 514 pp., 4 illustrations, 1 map. Henry G. Hanks ---- ----
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**July-October, 1932. (Ventura County). Report accompanying Geologic Map of Northern Sierra Nevada. Fossil Plants in Auriferous Gravels of the Sierra Nevada. Glacial and Associated Stream Deposits of the Sierra Nevada. Jurassic and Cretaceous Divisions in the Knoxville Shasta Succession of California. Geology of a part of the Panamint Range. Economic Report of a Part of the Panamint Range. Acquiring Mining Claims Through Tax Title. The Biennial Report of State Mineralogist ---- ----

Chapters of Report XXIX, 1933 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

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Tungsten Properties in California, accompanying July-October, 1942, Chapter of Report XXXVIII (showing California geology uncolored), sold separately ----------------------Price $0.60, sales tax $0.02	.62
Santa Cruz Co. Map, accompanying report on mines and mineral resources of Santa Cruz County in January, 1943, Chapter of Report XXXIX, sold separately ----------------------Price $0.15, sales tax $0.01	.16
San Benito Quadrangle Geologic Map, accompanying report on geology of area in April, 1943, Chapter of Report XXXIX, sold separately Price $0.40, sales tax $0.01	.41
San Bernardino County Map, accompanying report on mines and mineral resources of San Bernardino County in October, 1943, Chapter of Report XXXIX, sold separately--------Price $0.15, sales tax $0.01	.16
Manganese Deposits (showing California geology uncolored), accompanying Bulletin 125, sold separately---------Price $0.60, sales tax $0.02	.62
Jamesburg Quadrangle and Structure Section, accompanying report on geology of area in April 1944, Chapter of Report XL, sold separately Price $0.40, sales tax $0.01	.41
Riverside County, accompanying report on mines and mineral resources of Riverside County in July 1945, Chapter of Report XLI, sold separately Price $0.15, sales tax $0.01	.16

OIL AND GAS FIELD MAPS

The following maps are on sale at the State Division of Oil and Gas, Ferry Building, San Francisco, and the various branch offices. The maps are revised as development work advances and ownerships change. Price includes postage and sales tax.

No.		*Price*
1	Sargent, Santa Clara County	$0.75
2	Santa Maria, including Cat Canyon—Los Alamos, Santa Barbara County	1.25
3	Santa Maria, including Casmalia and Lompoc, Santa Barbara County	1.25
4	Brea Olinda and East Coyote, Los Angeles, Orange Counties	1.25
6	Salt Lake—Beverly Hills, Los Angeles County	1.25
7	Sunset, including San Emidio, Kern County	1.25
8	South Midway, including Buena Vista Hills, Kern County	1.25
9	North Midway and McKittrick, Kern and San Luis Obispo Counties	1.25
10	South Belridge and McKittrick-Temblor oil fields, Kern County	1.25
11	Lost Hills and North Belridge, including Antelope Hills, Kern County	1.25
12	Devils Den, Kern County	1.00
13	Kern River and Kern Front fields, including portion of Poso Creek field, Kern County	1.00
14	Coalinga Jacalitos, and East Coalinga Extension, Fresno County	1.50
15	Elk Hills, Kern County	1.25
16	Ventura County, Ventura and Rincon	1.75
17	Santa Paula-Ojai, including South Mountain, Ventura County	1.25
18	Sespe-Piru-Simi, including Bardsdale, Ventura County	1.50
18a	Newhall, Aliso Canyon, Newhall-Potrero, Del Valle and Oak Canyon, Los Angeles County	1.25
19	Arroyo Grande, San Luis Obispo County	1.00
20	Long Beach, Los Angeles County	1.75
21B	District 5, boundaries of areas including oil fields, Fresno, Kings and Kern Counties	1.00
21C	District 4, boundaries of areas including oil fields, Kern, Kings and Tulare Counties	1.25
22	District 3, boundaries of areas including oil fields, Santa Barbara County	.75
23	District 2, boundaries of areas including oil fields, Ventura County	1.00
24	District 1, boundaries of areas including oil fields, Los Angeles and Orange Counties	1.00
26	Huntington Beach, Orange County	1.50
27	Santa Fe Springs, Los Angeles County	1.25
28	Torrance, Los Angeles County	1.25
28a	Townlot area, Torrance field, Los Angeles County	.75
29	Dominguez, Los Angeles County	1.00
30	Rosecrans, Los Angeles County	1.25
31	Inglewood, Los Angeles County	1.25
32	Seal Beach, Los Angeles and Orange Counties	1.25
34	Mt. Poso and Poso Creek, Kern County	1.00
35	Round Mountain, Kern County	1.00
36	Kettleman North Dome and Middle Dome, Fresno and Kings Counties	1.50
37	Montebello, Los Angeles County	1.00
38	Whittier, Los Angeles County	1.25
39	West Coyote Oil Field, Los Angeles and Orange Counties	1.25
40	Elwood, Goleta (abandoned), La Goleta (gas), Santa Barbara County	1.25
41	Potrero, Los Angeles County	1.00
42	Playa del Rey, Los Angeles County	1.50
43	Capitan, Santa Barbara County	1.00
44	Mesa, Santa Barbara County	1.50
46	Richfield, Orange County	1.25
48	Mountain View and Edison, Kern County	1.25
49	Fruitvale, Kern County	1.00

OIL AND GAS FIELD MAPS—Continued

No.	*Price*
50—Wilmington, Los Angeles County	$1.25
51—Santa Maria Valley, Santa Barbara County	1.00
52—El Segundo and Lawndale, Los Angeles County	1.50
53—Rio Bravo and Greeley, Kern County	1.00
54—Wasco oil field, Buttonwillow and Semitropic (gas), Kern County	1.25
55—Canal, Canfield Ranch, Coles Levee, Strand, Ten Section, Kern County	1.25
56—Paloma, Kern County	1.25
57—Rio Vista (gas), Sacramento, Solano, and Contra Costa Counties	1.00
58—Trico Gas, Kern, Kings and Tulare Counties	1.00
59—Raisin City, Helm and Riverside, including Lanare area, Fresno County	1.25
60—West Newport and Newport, including Costa Mesa Area, Orange County	1.50
61—Wheeler Ridge and Tejon, Kern County	1.00

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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

W. BURLING TUCKER State Mineralogist

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OF

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QUARTERLY CHAPTER
OF
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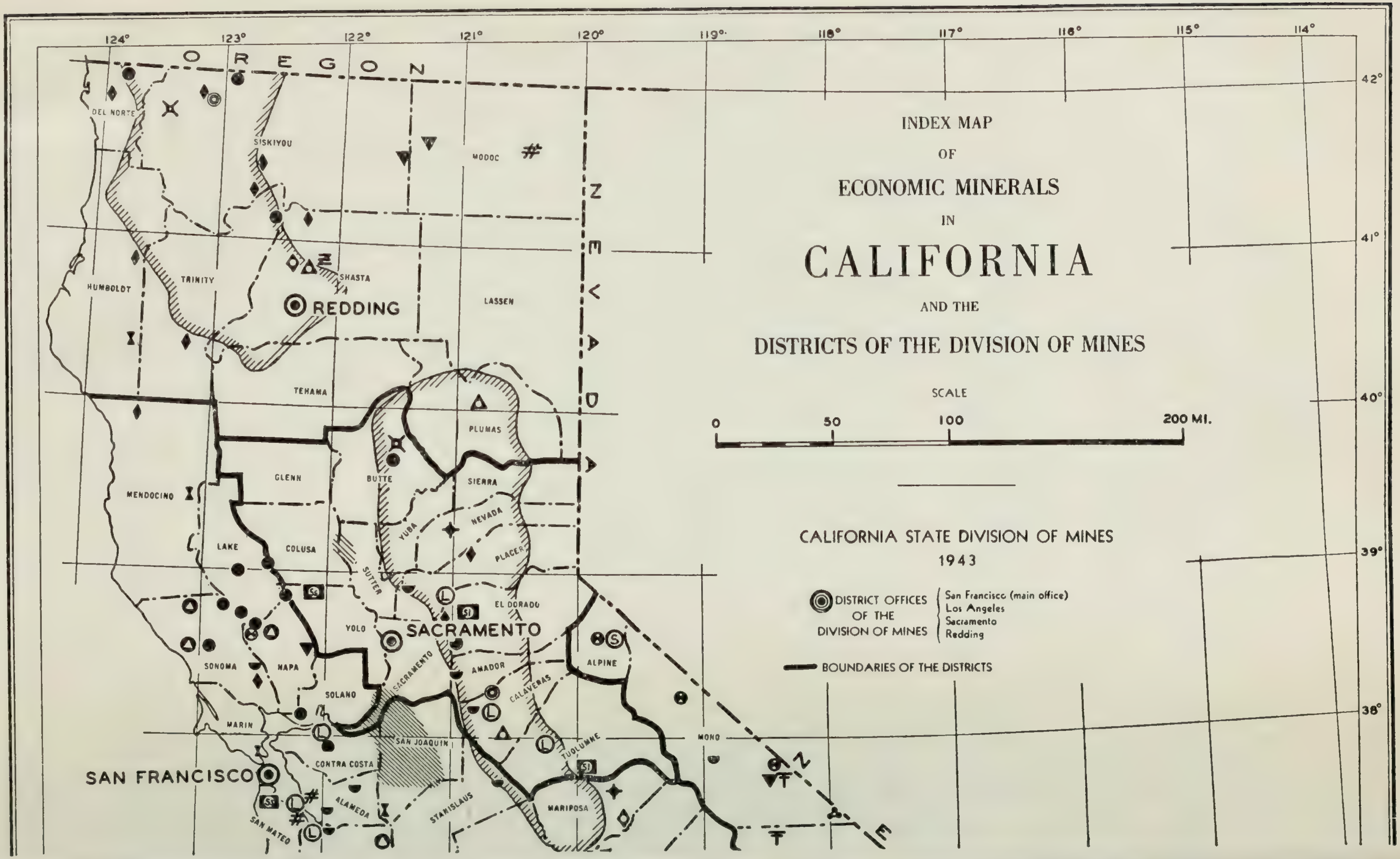
CONTENTS

PLATES


INDEX MAP
OF
ECONOMIC MINERALS
IN
CALIFORNIA
AND THE
DISTRICTS OF THE DIVISION OF MINES
SCALE
0
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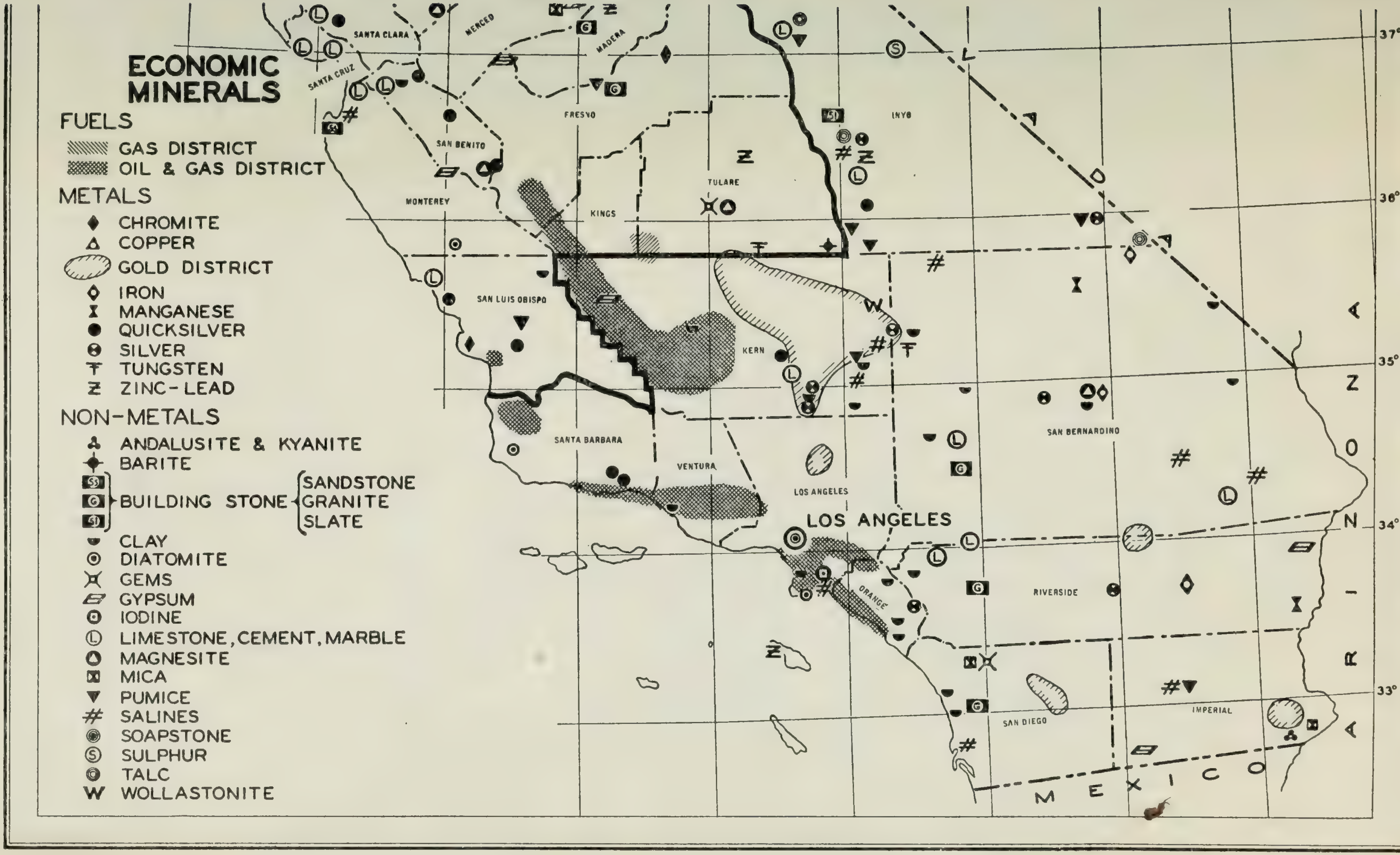
200 MI.
CALIFORNIA STATE DIVISION OF MINES
1943
DISTRICT OFFICES OF THE DIVISION OF MINES
San Francisco (main office)
Los Angeles
Sacramento
Redding
BOUNDARIES OF THE DISTRICTS
OREGON
NEVADA
124°
123°
122°
121°
120°
119°
118°
117°
116°
115°
114°
42°
41°
40°
39°
38°
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
REDDING
LASSEN
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
MENDOCINO
NEVADA
YUBA
LAKE
COLUSA
PLACER
SUTTER
EL DORADO
YOLO
SACRAMENTO
ALPINE
SONOMA
NAPA
AMADOR
SOLANO
CALAVERAS
MARIN
SAN JOAQUIN
MONO
TUOLUMNE
CONTRA COSTA
SAN FRANCISCO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO


ECONOMIC MINERALS
FUELS
GAS DISTRICT
OIL & GAS DISTRICT
METALS
CHROMITE
COPPER
GOLD DISTRICT
IRON
MANGANESE
QUICKSILVER
SILVER
TUNGSTEN
ZINC-LEAD
NON-METALS
ANDALUSITE & KYANITE
BARITE
BUILDING STONE
SANDSTONE
GRANITE
SLATE
CLAY
DIATOMITE
GEMS
GYPSUM
IODINE
LIMESTONE, CEMENT, MARBLE
MAGNESITE
MICA
PUMICE
SALINES
SOAPSTONE
SULPHUR
TALC
WOLLASTONITE
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
FRESNO
INYO
SAN BENITO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
NEVADA
ARIZONA
MEXICO
37°
36°
35°
34°
33°

ADMINISTRATION

ADMINISTRATIVE REPORT

By W. B. Tucker, State Mineralogist

Personnel

Walter W. Bradley, State Mineralogist, retired July 31, 1946, after continuous service with the California State Division of Mines (formerly the State Mining Bureau), dating from January 8, 1912. During this period he served as Librarian, Field Assistant, Mining Statistician and Curator, Assistant Mining Engineer, and Deputy State Mineralogist. He was appointed State Mineralogist by Fred Stevenot, Director of the Department of Natural Resources, August 1, 1928, and served as State Mineralogist for 18 years, until his retirement. During his administration there has been noteworthy expansion of the activities of the Division of Mines, and of services rendered to the public and mining industry of the state.

Mr. Bradley is author of a great number of technical reports and special articles on the mineral resources of California published in the *California Journal of Mines and Geology*. Nearly all of the annual Reports of the State Mineralogist issued since 1916 contain articles written by him. He is also author or co-author of the following technical bulletins issued by the State Division of Mines:

Bulletin 78, *Quicksilver Resources of California*, including a section on metallurgy and ore-dressing.

Bulletin 79, *Magnesite in California*.

Bulletins 71, 74, 83, 86, 88, 90, 93, 94. 96, 97, and 100, *California Mineral Production*, statistical bulletins covering the period 1915-26 inclusive.

Bulletin 76, *Manganese and Chromium in California*, co-author.

Bulletin 130, *Economic Mineral Resources and Production of California*, co-author.

Bulletins 98 and 123, *American Mining Law*, co-author with A. H. Ricketts.

Bulletin 131, *Consolidated Index of the Publications of the California State Division of Mines*, in press.

Mr. Bradley has also written numerous articles for publication by the American Institute of Mining and Metallurgical Engineers, and for other scientific organizations and magazines. Under his administration the 1938 geologic map of California, prepared by Olaf P. Jenkins, was issued.

He has been a true public servant, and has an outstanding record of long and faithful service to the state.

W. Burling Tucker, District Mining Engineer of the State Division of Mines at Los Angeles, was appointed to fill the position of State Mineralogist, August 12, 1946. He has been on the staff of the Division of Mines from October 1913 to date. From May 1923 to August 1, 1946, he has had supervision of the southern California district, with offices at Los Angeles. He has published reports on mineral resources of the following counties: Amador, Calaveras, Tuolumne, El Dorado, Lassen, Modoc,

Tehama, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara, and Ventura.

Clarence R. King was appointed Associate Metallurgical Engineer on the Division of Mines staff in July 1946, his duty being primarily to conduct the survey of markets for California minerals. Mr. King graduated from the University of California in 1922; was mill superintendent for California Rand Silver, Inc., Randsburg, California, from 1923 to 1925; chief engineer for Zenda Gold Mining Company, California, 1925-26; research metallurgist for United Verde Copper Company, Arizona, 1929-35; operated mining properties in Chihuahua, Mexico; was chief field agent, Northern Mexico, for Polaroid Corporation on procurement of optical calcite, 1943-44.

Roy J. Nielsen was appointed Librarian on the Division of Mines staff, September 16, 1946. Mr. Nielsen graduated from the University of California at Berkeley in December 1939 with an A. B. degree in Geological Sciences. After 8 months of work with United States Department of Agriculture, he returned to the University of California at Berkeley, and took a year of work in librarianship, receiving a certificate of librarianship.

Edward J. Rhodes was appointed Geological Draftsman on the Division of Mines staff, September 20, 1946. He graduated from Massachusetts Institute of Technology, Boston, Massachusetts, in 1931; worked at Massachusetts Institute of Technology as Geological Draftsman from January 1932 to June 1935; from June 1935 to September 1940 he was with the United States Engineers, as Draftsman and Junior Geologist, at district offices in Boston, Massachusetts, and Cincinnati, Ohio; from September 1940 to March 1946 he was in U. S. Army, where he received a commission of Captain, in the Ordnance Department.

LOS ANGELES FIELD DISTRICT

CURRENT NOTES

By W. B. Tucker, State Mineralogist

INYO COUNTY

Millspaugh iron deposit comprises three claims, located as Big 4 Iron No. 1, Big 4 Iron No. 2, and Big 4 Iron No. 3, situated on the west slope of Argus Mountains in T. 22 S., R. 42 E., M. D., 23 miles south of Darwin; elevation is 6200 feet; owner is Nathan Burton of Los Angeles.

Three lenses of high-grade hematite occur in a porphyry dike in granite, striking N. 40° W., and dipping 40° to 60° SW. The porphyry dike has a width of 20 feet, and the hematite occurs in irregular lenses in the dike. The width of these individual lenses of iron ore is from 4 to 6 feet. The granite is also cut by a series of intrusive diorite dikes. These diorite dikes strike N. 40° E. and cut the porphyry dike where the vein is exposed by three shallow open cuts. Development consists of open cuts on No. 1, No. 2, and No. 3 claims. The open cuts are 6 to 8 feet in depth and 20 feet in length.

On Big 4 Iron No. 1 claim, an open cut exposes 4 feet of high-grade hematite with a probable length of 200 feet. On Big 4 Iron No. 2 claim, hematite is exposed by two open cuts 8 feet wide, and with outcrop about 200 feet in length. On Big 4 Iron No. 3 claim, the outcrop is about 150 feet in length, and where exposed by open cuts has an average width of 6 feet.

Analysis of the ore by California Testing Laboratories, Los Angeles, is as follows:

Iron (Fe)	67.0 %
Silica (SiO_2)	4.8 %
Sulphur (S)	0.01%
Phosphorus (P)	0.03%

A composite sample taken by Don Hill, E.M., Kaiser Co., Inc. assayed 66 percent Fe.

The deposit is idle at the present time.

SAN BERNARDINO COUNTY

Tiefort Mountains iron deposit is situated on the north slope of the Tiefort Mountains, in sec. 22?, T. 14 N., R. 4 E., S. B., 4 miles east of Bicycle Lake, 14 miles east of U. S. Army Camp Irwin, and 51 miles northeast of Barstow, at an elevation of 2500 feet. One claim, known as Bicycle Lake lode claim, was located by John H. Whitlock of Los Angeles, and Donald H. Fry of South Pasadena, in February 1946. A high-grade deposit of hematite occurs in gneissoid granite; the outcrop is 1000 feet in length and 75 feet in width. The strike is N. 45° W., the dip 60° SW. Development consists of a shaft 15 feet in depth sunk on the footwall side of the iron outcrop, and two short tunnels driven at different elevations. The estimated tonnage of iron ore is about 200,000. Analysis of a sample of ore by Kaiser Company, Inc., Fontana, California, is as follows:

Iron (FeO_3)	68.20 %
Sulphur (S)	0.022%
Silica (SiO_2)	1.37 %
Phosphorus (P)	trace

GEOLOGIC BRANCH

CURRENT NOTES

By Olaf P. Jenkins *

In this issue

The following treatise on the famous Kramer borate district, as prepared for this issue of the Journal by Mr. Hoyt S. Gale, is particularly significant because borax represents one of the great mineral products of California, and this state supplies most of the world's output of borax. Increases in the uses of borax point to a distinctly favorable future for the industry. From a mineralogical standpoint, the Kramer district is famous since its principal borax mineral, kernite, has been found nowhere else but in this one locality. Geologically, the description of the Kramer borax formations is particularly interesting since the formations are not exposed and therefore can not be studied on the surface. To beneficiate the ore mineral, water is added to form commercial borax; whereas with most ore minerals the effect of treatment causes reduction.

It is a satisfaction to know that the Federal Geological Survey now has established a Map Information Office in Washington. The following article, released by Colonel Gerald FitzGerald of the Topographic Branch of the Geological Survey, is published in this issue of the Journal to inform the public of this much-needed new service.

Recent bulletin

Bulletin 133, *Geology of the San Juan Bautista quadrangle, California,* by John Eliot Allen, is now published and will be made available as soon as the principal map arrives from the lithographer. The bulletin contains, among other illustrations and maps, a colored geologic map of the quadrangle printed on the topographic base. It is the third map of a series now being issued by the Division of Mines; the other two maps of this series being the San Benito and Jamesburg quadrangles. The economic mineral resources are described in this report: limestone and dolomite, crushed rock, sand and gravel, black sands, barite, and oil. An interesting report by Royal E. Fowle, *Operations of the Granite Rock Company quarry and plant at Logan, San Benito County,* is included also in this bulletin. The huge quarry described is in granite, crushed naturally by movements of the San Andreas fault, which runs directly through the deposit. As a basic study, Bulletin 133 should prove to be of long-lasting usefulness.

In press

The first chapter of the first part of Bulletin 134, *Geological investigations of chromite in California,* is now in press. This chapter is included under Part I, Klamath Mountains, and is entitled *Chromite deposits of Del Norte County,* by Francis G. Wells, Fred W. Cater, Jr., and Garn A. Rynearson. A topographic map of Del Norte County is included, showing the serpentine areas and the chromite deposits included in this rock formation. The publication is a part of the State-Federal cooperative geological project.

* Chief Geologist, Division of Mines.

THE MAP INFORMATION OFFICE OF THE GEOLOGICAL SURVEY*

By C. F. Feuchsel **
United States Department of the Interior, Geological Survey

The desirability of coordinating the surveying and mapping activities of the Federal Government was recognized many years ago. After the first World War the Federal Board of Surveys and Maps was created by Executive order upon the recommendation of the major map-using and map-making agencies. Among other stipulations this order directed the Board to

> ". . . establish a central information office in the Geological Survey for the purpose of collecting, classifying and furnishing to the public information concerning all map and survey data available in the several government departments and from other sources . . ."

This was quite an order—particularly in view of the limited allotments subsequently made available. However, the Federal Board and Map Information Office functioned within their authorized correlative and advisory capacities—as well as financial limitations—until the Board was abolished by Executive order early in 1942. Its functions were assigned to the Bureau of the Budget at whose request the Map Information Office has been maintained by the Geological Survey, though in dormant status during the war.

General recognition is again prevalent that a central and authoritative source of information pertaining to maps, surveys, and aerial photographs is most necessary, and to that end the Geological Survey is greatly expanding such facilities. Opinions of those outside the Survey regarding the appropriate scope of coverage that this focal point should afford, range from summary generalities, which could be maintained by several specialists, to the most intensive research, record-keeping, evaluation, and distribution of the product which would involve a bureau-sized structure of some hundreds of employees. In view of the current volume of bona fide and rational service requests, the reasonable facility for the immediate future—keeping practical limitations in mind—will involve from 20 to 30 employees. With an organization of this size, requirements anticipated during the coming year from our production units, other agencies, and the general public may be met. A constantly increasing volume of requests for information has been evident during the past few months, however, and it is likely that one year hence a considerably larger organization may be necessary.

Before proceeding with a discussion of our specific Map Information objectives it may be of interest to quote from a resolution, passed last year at the annual meeting of the American Geophysical Union, suggesting the establishment of a Federal Map Information and Distribution Office:

> ". . . . Whereas, the map-using public is at present seriously handicapped by its inability to obtain all topographic maps from a single source as

* Published by permission of the Director, Geological Survey, Department of the Interior. Paper presented at the sixth annual meeting of the American Congress on Surveying and Mapping, June 28-29, 1946, in Washington, D. C. Manuscript submitted for publication August 12, 1946.

** Chief of the Map Information Office, U. S. Geological Survey.

formerly, or to obtain definite information as to what agency distributes the maps or charts needed and is therefore frequently put to unnecessary expense and annoying delay in securing these maps or charts, be it therefore

"*Resolved*, that the American Geophysical Union recommends the formation, within the framework of existing federal agencies, of a map information and distributing office responsible for furnishing accurate and complete information regarding all maps, charts, and aerial photographs published or procured by the federal surveying and mapping agencies; and for the actual distribution of all topographic maps of the United States and its possessions now published and distributed to the public by numerous federal agencies . . ."

ORGANIZATION

The Map Information Office of the Geological Survey has now been established as a Section of the Planning and Coordinating Staff of the Topographic Branch. Within the office four specialized units have been developed to cover their designated fields of responsibility, namely: Topographic Maps, Aerial Photography, Geodetic Control, and General and Foreign Maps.

TOPOGRAPHIC MAPS UNIT

The prime responsibility of the Topographic Maps Unit is research for all topographic data pertaining to the United States and its possessions, which have been produced by any government or commercial organization.

It has become more and more evident in recent years that substantial savings in new mapping operations alone more than justify this initial investment of effort. The actual search must be followed by the systematic assembly and evaluation of all discovered data to facilitate ready and appropriate use. The now prevalent photogrammetric procedures require this assembly of data for the efficient performance of the whole sequence of mapping phases, namely, aerial photography, control planning and survey, stereo-plotting, field completion, and editing. Heretofore, such basic information, though very desirable, was less vital to the successful completion of projects carried by plane-table mapping procedures. This initial product of the mapping operation is, of course, made available to other agencies and to the general public in the same manner as the end product—the topographic map.

Perhaps the most complex phase of the preparatory work just outlined is that of map evaluation which, as an initial step, involves the development of practicable criteria for determining map adequacy. Nearly half of the United States is topographically mapped in some manner and a thorough-going classification of these data is needed for public use as well as for the planning of comprehensive projects and establishment of priorities for new mapping. The publication of a series of index maps showing various phases of the status of mapping is planned for the near future.

The appraisal of map *adequacy*, is inevitably associated with map *accuracy* standards. However, the accuracy standards now employed are more appropriately applied to maps produced in very recent years rather than to the older surveys which were accomplished with lower cost and accuracy standards to meet the general requirements of earlier years. Yet such maps have a high utility value for certain present-day requirements. It therefore appears necessary to maintain a general index of map usability until the country is covered with relatively high-grade surveys, at

which time the accuracy compliance records will suffice as an index of actual utility. The Geological Survey is now making an over-all study of the status of topographic mapping from the actual utility standpoint.

The Topographic Maps Unit, in addition to the research and evaluation work just described, maintains a complete file of all topographic maps produced by the Geological Survey together with their compilation histories. The maintenance of a bibliography of established and current literature dealing with standards, procedures, and other information related to topographic mapping, is also the assigned responsibility of this unit as well as the ultimate preparation of a comprehensive map catalogue. The latter item must be regarded as an end product of the basic research and assembly of materials which is now under way, and will be completed during the coming year.

AERIAL PHOTOGRAPHY UNIT

The primary responsibility of the Aerial Photography Unit is the assembly of complete information regarding the existing aerial photographic coverage of the United States and its possessions. Records of the coverage obtained by the Department of Agriculture and certain other Federal agencies are already in good order; but much coverage obtained by state, city, and commercial organizations is now unrecorded at a central reference point. Work of this nature is now well under way.

In addition to recording information on available coverage, date of photography, and film-holding agency, which is our immediate objective, we hope to eventually maintain supplementary data such as flight altitude, focal length of lens, and information on mosaics and other by-products. Only summary generalities regarding the aerial photography available for foreign areas will be maintained, sufficient, however, to service geologic and other special projects of the Survey which may arise in foreign areas.

Perhaps the largest potential work item of the Aerial Photography Unit is that of preparing copies of Survey photography to meet the requests of other agencies and the general public. While this is not a heavy obligation at the present time, the Survey's mapping coverage will be very greatly extended during the coming years and substantial laboratory and film storage facilities will be required to meet public orders.

CONTROL UNIT

The assembly of all horizontal and vertical control data which can be used in the preparation of topographic maps, will be one of the responsibilities of the Control Unit. The necessary coverage indexes and other records will be maintained to service our production units and this information will be available to others for reference purposes. All control produced by Geological Survey parties will be duplicated in quantity and distributed to the public by this Unit. State indexes, showing the general locations of all existing horizontal and vertical control, will also be maintained and, if demands justify, published for distribution.

GENERAL AND FOREIGN MAPS UNIT

Since the Library of Congress, Army Map Service, and others already maintain extensive files and coverage records of foreign areas, only general summary data are maintained by the General and Foreign Maps

Unit, to facilitate the referring of inquiries to the appropriate holding agency. The "general" maps, however, including those other than topographic which pertain to the United States and possessions, are covered in detail to support Survey operations. Preliminary assemblies are made of data suitable for project planning, aerial photography, and control lay-outs. Other production units subsequently require the most authentic information pertaining to political boundaries, nomenclature, road classifications, and so forth, to facilitate compilation and editorial work.

Public requests for county, state, and regional maps covering a wide variety of specialties are now quite numerous. This indicates the desirability of maintaining a broad assembly and thorough classification of general coverage maps as an adjunct to the requirements of our own production groups.

GENERAL SERVICE UNIT

The preparation of exhibits, press statements on a wide variety of subject matter, arrangements for lectures and tours of Survey installations and a miscellany of related work has also been assigned to the new Map Information Office. Work of this nature will be assumed by a special unit soon to be activated.

The foregoing summary of functions now aligned for Map Information covers the consensus regarding the scope of information and public service that should be available from Federal sources, preferably at one central point. It does *not* imply, however, that the Survey intends to duplicate any established facilities which already cover well-defined sectors of the field. Rather, a survey of facilities maintained by the several Federal agencies is now being made to determine existing gaps in the over-all requirements and to plug such gaps by assembling the necessary data within the Map Information Office.

Meanwhile, in connection with our survey of facilities existing outside the Geological Survey, coverage indexes and other pertinent data are being recorded in order that public requests for information may be accurately referred to the specific agency and unit holding the particular item of interest when detailed information from the producing agency is required. By this means a satisfactory service may be rendered without building an organization of unreasonable size. Many of the stated functions, such as the distribution of survey control and aerial photography, as well as the maintenance of various records, are now covered by other units of the Geological Survey and in such cases a mere administrative shift of personnel and facilities will be involved when our current reorganization is achieved.

GEOLOGY OF THE KRAMER BORATE DISTRICT, KERN COUNTY, CALIFORNIA

By Hoyt S. Gale*

OUTLINE OF REPORT

ABSTRACT

Deposits of borate minerals, discovered in 1913 in the vicinity of Kramer in southeastern Kern County, California, have proved to be the most important mineral source of borax and borate products, not only in the United States but in the whole world. Since 1926, when the remarkable deposits of crystalline sodium borate were first opened by mining operations, a total of approximately 2,000,000 short tons of crude borate materials of an estimated average content of 40 percent anhydrous boric acid has been produced. This has been derived from 3 mines, each developed independently but now consolidated under the ownership or control of the Pacific Coast Borax Company, or really under Borax Consolidated of London.

The borate deposits are not found in outcrop, but lie beneath the surface in an area covered by alluvial wash characteristic of desert surfaces, consisting of sand, gravel, and clays such as are distributed by flowing streams. As developed by drilling and mining, the borate deposits lie within an irregularly oval area about 4 miles in length from east to west and 1 mile in width from north to south. This area was apparently an original basin of deposition during the epoch in which the borates accumulated, and has been moderately deformed since that time, so that the beds lie in a synclinal basin now depressed to depths of 1000 feet and more along its axis. The principal borate deposits range in depth from about 300 to 1000 feet below the surface of the ground.

The loose, unconsolidated alluvial deposits that cover the surface in the vicinity of the borate deposits extend to a maximum depth of 300 feet, so far as known. Tertiary beds encountered at the base of the alluvium are very like the alluvium in composition.

* Consulting geologist, Los Angeles, California. Manuscript submitted for publication May 1946.

They consist of an alternation of sediments deposited by flowing or standing waters, underlain by flow lavas of olivine basalt, the lavas including some interbedded sediments like those above. The borate deposits are included in the sedimentary part of the section that overlies the lavas. These Tertiary sediments, continuing in their upper part into coarser sands, granite, and conglomerate, are distinguished from the alluvium chiefly by their firmer consolidation, and by an unconformity that exists between the two. The borate-bearing beds are presumably of upper Miocene age, and are classed as a part of the Ricardo formation.

The borate deposits occur in a distinctive series of sedimentary beds or units designated as the Kramer lake beds. The members of this zone are locally identified, from the top down, by the terms "green shale", "blue shale", which includes the borates, dark-gray shale underlying the main borate deposits, and the flow beds of basaltic lava which are usually found at the base of the borate section. The maximum thickness of this lake-bed section is probably about 350 feet above the top of the underlying lava, but the finer clay or shale that is associated with the borates thins and is replaced by coarser detrital sediments around the borders of the area that contains the borates. This "blue shale" is a fine sediment of colloidal type, sometimes found to contain grains or particles of basaltic material, as well as other coarser detritus, but is evidently a deposit laid down in standing water, as in the bed of a playa or intermittent lake. The basaltic lavas that immediately underlie the borate deposits and seem to be a part of the same depositional sequence, rise in dip-slope outcrops around the northern borders of the basin in which the borates are found. These flows vary in thickness from 600 feet maximum as seen in the outcrops, to where they apparently pinch out and disappear in an area along the southern border of the basin to which they probably did not originally extend. They have been included under the designation of Saddleback basalt.

The borate-bearing section, including the associated underlying lavas, shows moderate or open deformation, not only in the down-warp of the main syncline in which the deposits are preserved, but also by subsidiary folding and minor faulting. The dips of these beds, as developed in the mines, show folds, usually anticlinal where the main deposits opened by the mines were encountered, with inclination on the flanks ranging up to 8 or 10 degrees, and in some places much steeper. A system of northwest-trending faults cut the borate-bearing beds, apparently throughout the entire district, and are found not only in the mines but also in the older rocks that outcrop around the borders of the basin.

Colemanite and ulexite are the most widely distributed of the borate minerals. These are scattered irregularly in the form of nodules or lumps, embedded in the clay or shale already mentioned. These mineral deposits were probably formed in essentially the same way as other deposits of similar type that were formerly mined in the western part of the United States. The peculiar cancer-like growth of soft, radially fibrous lumps of ulexite known as cottonball, that form within the loose, moist soil about the margins of certain playas is well known. Modern deposits of this type are "pockety", apparently localized within certain areas of rising ground water, and are found in certain districts where late Tertiary vulcanism is apparent. It seems clear that the ulexite of the Kramer district was formed during late Tertiary time in essentially the same way as the modern deposits of this mineral are formed, in or on the borders of playas, and that the ulexite was in places converted to colemanite after burial of the original deposits. Colemanite, found only in Tertiary formations in clays similar to those in which the modern deposits of ulexite are formed, has been shown to be an alteration from original ulexite, recrystallized almost in situ, with some shrinkage; thus open spaces are frequently left, which characteristically contain geodes lined by beautifully terminated crystals of colemanite. Colemanite is also formed as fissure fillings, in vein structure, but these occurrences are subordinate to the main deposits in the nodular forms. Most of the area classed as borate-bearing contains only sporadic occurrences of the calcium borate minerals colemanite and ulexite, which were the minerals first found and developed in the Kramer area.

The deposits of the two sodium borate minerals tincal or native borax and kernite, found later, have proved to be by far the most important, and have yielded almost the entire output from the district. These deposits of massive crystalline sodium borate, containing subordinate amounts of clay as gangue or other impurities, occur in the form of tabular beds or layers more or less interbedded with sediments, ranging up to a total of 250 feet in thickness at places. These bodies of sodium borate lie within a smaller area than that in which the calcium borate minerals are found, all within the same outer limits of the oval area referred to above. The sodium borate bodies are abruptly lenticular in outer form, terminating against the surrounding sediments as though lapping against an original shore line.

Where seen in simplest form, with least deformation or alteration, the borate material is tincal or native borax, regularly interstratified with clay or sediment. The preponderance of this single water-soluble salt in these massive crystalline bodies, without appreciable contamination by any other soluble constituent, is—to say the least—remarkable. The crystallization of the borax in layers, the frequent orientation of crystals with reference to a base in these layers, and the intermittent covering of such layers of crystals by thin beds of silt or clay, seem to leave no room for doubt that originally these deposits were laid down by crystallization directly out of solution in an open body of water. When the outline of the sodium borate bodies is more fully known, the extent of these former lakes or lagoons will be seen. After accumulation of this chemically deposited borax had gone on for a certain period of time, the deposits were covered by overwash of sediments, and this continued until the borates were buried to the depth of some hundreds of feet with detritus washed from adjoining hillslopes.

It is generally accepted that boron or borate salts have been brought to the earth's surface with volcanic gases or waters in a volcanic region. At Kramer, it seems obvious that the waters that deposited the borates issued with and subsequent to the outpouring of the Saddleback basaltic lava over slopes adjacent to the basin in which the lake deposits were later laid down. Volcanic waters probably flowed down through and over the lava flow masses while these rocks were still hot. Thus these waters may have concentrated rapidly by evaporation as they passed on down toward nearby basin areas, and may have accumulated in pools or lakes at the low part of the basin in a supersaturated condition with respect to borax. Spreading out into a broad surface exposed to the air the waters in the lake or pool may have undergone a relatively sharp drop of temperature, thereby throwing out borax (as tincal) while other salts remained in solution, in all essential respects like the separation of borax by cooling of hot solutions of mixed salts in the old marsh borax separation processes. Continued inflow of heated solution and overflow of surplus waters from some low point in the margin of the basin, disposed of practically all salts other than borax. It seems as if this is the only logical explanation of the precipitation of crystalline borax, layer by layer, with minor interbands of sediment, as it occurs in the Kramer deposit.

Kernite seems to have been formed from the original bedded accumulations of native borax by alteration and re-crystallization of the sodium borate after the deposits had been buried and rather firmly consolidated. This new mineral, first found in the Kramer area, is of the same composition as borax except that it contains less combined water. Where the kernite exists the deposit generally shows internal disturbance of the structure. The mineral is crystallized in such a way as to show that it was introduced into the sedimentary matrix after the consolidation and deformation of the latter. There is some evidence of solution, and replacement of the shale, to make room for the kernite which was formed. Perhaps the force of growing crystals of kernite produced some of the disturbance evident in the matrix. This alteration of borax to kernite is found in only two of the three mines now opened in the district. Where kernite is found, it is usually mixed with tincal (native borax). In these associations some large masses of tincal are obviously secondary to the kernite, and study in the Western Borax mine led to the conclusion that practically all of the tincal exposed in the mine at that time was of secondary origin. This is shown by pseudomorphs of tincal after kernite, large crystals retaining the outer form of kernite, partly or wholly converted to tincal. Some examples show the change in an arrested stage, with rounded cores of the original kernite lying within massive clearly crystalline tincal.

The chemical changes involved in converting one of these minerals into the other seem to be simply a subtraction of combined water for the formation of the kernite, and later an addition of the same amount of water to reconvert the kernite to tincal. Doubtless these reactions took place under cover of the blanket of the superimposed sediments, and the process was slow, wherefore the kernite formed in large crystals, and commonly displaced the matrix in its growth. A similar transformation seems to have occurred as between the sodium-calcium-borate minerals ulexite and probertite, the latter having the same composition as the ulexite but with a smaller amount of water of crystallization. With both sets of minerals these dehydration changes seem to have been reversible.

The deposits lie in the near vicinity of lately active eruptive volcanic vents and were laid down closely succeeding the outpouring of the later basaltic lavas that had previously covered much of the country in the vicinity of the places where the borate deposits were to form. The heat of active vulcanism may have had much to do with the alteration of the tincal to kernite. Subsequent access of ground moisture to parts of the deposit, following deformation, probably brought about the later reversal of the reaction.

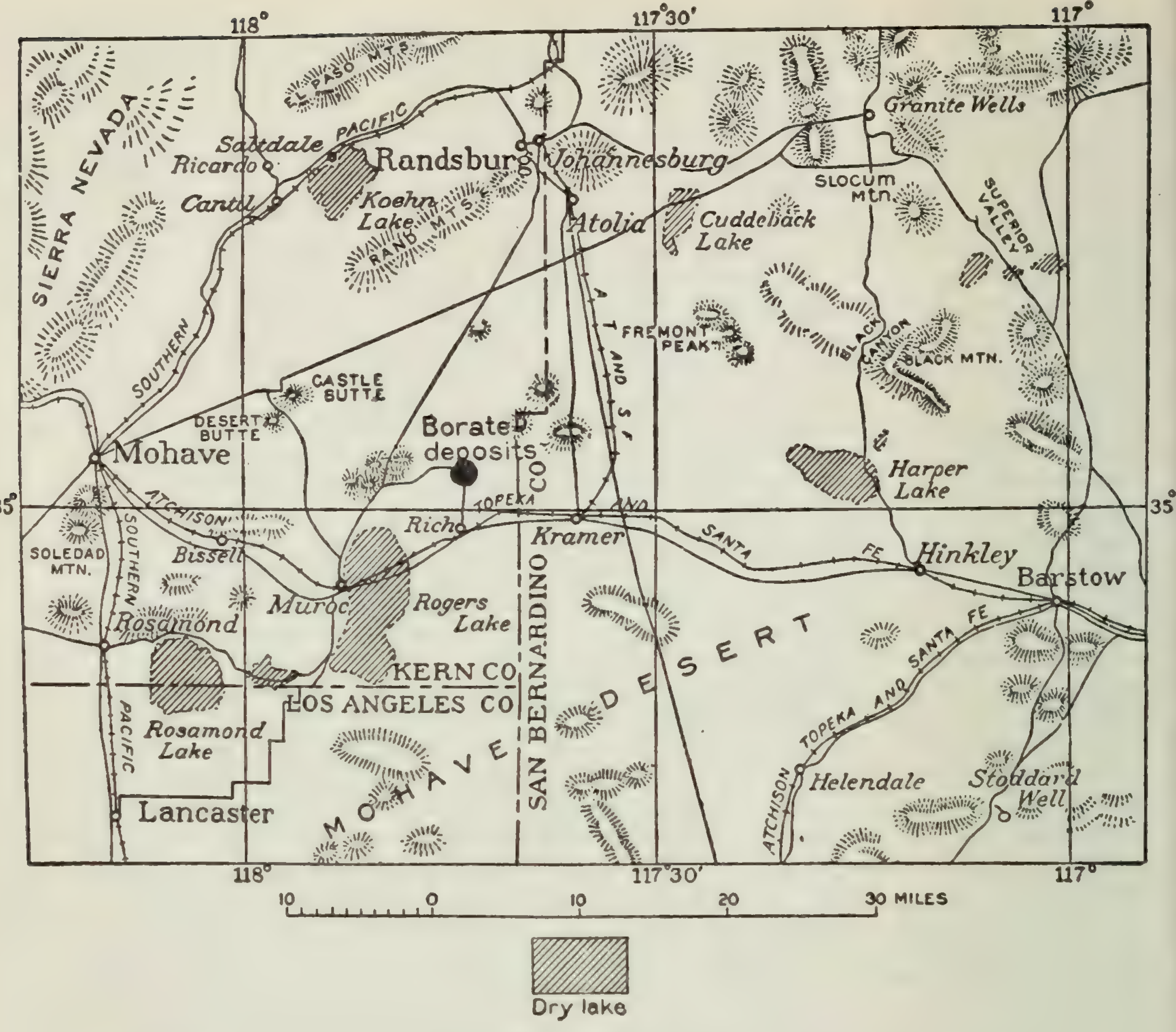


FIGURE 1. Index map showing location of Kramer borate deposits, Kern County, California

A Tertiary section, distinct from and definitely older than the borate-bearing section, underlies the borate-bearing sediments and their associated lavas. This is of supposed middle Miocene age. It is correlated with the Rosamond formation, the type section of which, as originally described, is not far distant. The beds contain characteristic marker members which indicate that this deposit was more or less continuous between the two districts. The Rosamond formation consists of tuffs and lavas, mostly of acid types in the lower part of the formation, these volcanic materials being intercalated with terrestrial sediments that are similar in a general way to the sediments of the borate-bearing section. The Rosamond sediments are generally more indurated than the overlying borate-bearing beds, and are commonly much more deformed. There is at places a distinct unconformity between the Rosamond and the overlying basaltic lavas and sediments that contain the borates. The Rosamond commonly shows steep dips in contrast to the gentle structure of the borate-bearing section. It appears that a considerable part of the Rosamond was removed by erosion before the borate-bearing sediments and their associated lavas were spread over the surface. Some hills of harder Rosamond beds stand as monadnocks above the present surface, and these appear to have stood above the surface on which the borate-bearing beds were being laid down, these older sediments being exposed and subject to erosion during the borate-accumulating epoch. An example of such monadnocks is in Water Tank Hill near the Western Borax mine. The Rosamond formation aggregates a thickness of 1500 feet or more in full development, but is generally very incompletely represented at any one place.

The Tertiary rests upon a foundation of older rocks, here called the basement complex. This consists chiefly of granitic rock classed as quartz monzonite, presumably of Jurassic age. It includes some older pyroclastics and lavas, the latter of relatively more limited distribution on the surface.

INTRODUCTION

Importance of the Kramer District

The remarkable deposits of the massive crystalline sodium borate that have been developed in the vicinity of Kramer in southeastern Kern County, California, are by far the largest, and in many other ways the most extraordinary occurrences of borate minerals that are known anywhere in the world. The other deposits in southern California and Nevada which before the development at Kramer had held a leading place in the borate supply of the world, and are not yet exhausted, have been almost entirely displaced by the output from the Kramer district together with the supply that is now produced from the brine at Searles Lake and a relatively small production from brine at Owens Lake. For approximately 15 years the output from the Kramer deposit has dominated the world market in borates. Since 1926 this district has yielded approximately 2,000,000 short tons of sodium tetraborate in natural crude form or with preliminary concentration at the mines, these being reported as customary with crude borate materials, on the basis of 40 percent anhydrous boric acid (B_2O_3). Reserves available for future production have not as yet been fully disclosed, but they are very great, probably at least 50 times the amount already taken out, and possibly much more than that.

Location

Kramer is a minor station on the Santa Fe Railroad, about midway between Mojave and Barstow, in the western part of the Mojave Desert. A branch railroad line leads northward from the main line at the junction known as Boron about 6 miles west of Kramer station, branch lines having been extended to each of the three mines of the district. The usual approach by road is over U. S. Highway 466. From the west the distance is 30½ miles from the town of Mojave to the small settlement and local supply point now called Boron, whence it is 3 miles north to the mines.

Discovery

Borate was discovered in the Kramer district in the Fall of 1913 as recorded by the location of a mining claim for borates by Otelia Suckow, covering 40 acres including a well drilled for water on a homestead claim. The calcium borate mineral colemanite was recovered from a depth of 370 feet in this hole. Subsequently colemanite with ulexite, the latter a sodium-calcium borate, were found in other borings and prospect shafts put down in the vicinity of the discovery; but the amounts of these minerals revealed during the next 12 years of nearly continuous exploration did not seem, at the time, of much commercial importance. It was not until 1925 that the great tabular body of crystalline sodium borate was discovered in a drill hole, and not until August 1926 that this great new type of borate deposit was reached in a shaft.

Chronology of Information Sources

The writer's particular interest in the subject of borax began in 1911 when, in collaboration with Charles G. Yale, senior authority on mineral production statistics, he undertook the collection of data on borates for publication in the annual chapter entitled *Borax* in *Mineral Resources of the United States,* then published by the United States Geological Survey. By chance passing through the Kramer district in the Fall of 1913, shortly after the discovery of colemanite there, he was told of the matter by local residents, but little actual information was available

at that time. This was reported in the chapters on borax for the years 1913 and 1914. After the writer's separation from Government service, Mr. A. Vogt and he made a visit to the Kramer district on November 4, 1920. Thereupon the writer compiled a report on developments for private interests, which led to his fairly continuous interest in the district from that time on.

Of many subsequqent engagements and visits to the Kramer borate area, the following are of possible historical interest. In May 1924, a shaft being put down by Dr. Suckow in sec. 22, T. 11 N., R. 8 W., S.B., reached colemanite and was later developed into the first commercial producer of borates from the Kramer field. In February 1926, the writer presented an account of developments in the Kramer district in a paper prepared for the meeting of the American Institute of Mining Engineers, which was published by the society (Gale, H. S. 26). L. F. Noble kindly accompanied the writer on two visits to the field at that time and as a result Dr. Noble (26) published a well-organized account of the geology of the area.

Although the massive deposit of crystalline sodium borate was discovered in 1925, practically no information about these minerals was available until later, when the new sodium borate mineral was given the name kernite (Schaller, W. T. 27, p. 24). This new form of borate deposit was opened by the Pacific Coast Borax Company in the latter part of 1926.

At about this time a shaft was being put down by Dr. Suckow in the southeastern part of section 14, west of the borax company mine, which encountered massive beds of natural borax interbedded with lake-bed shale. In May 1927, the writer was called upon by W. M. Balling to make an examination and report on the S½ sec. 24, T. 11 N., R. 8 W., S.B., south of the recently opened mines of Pacific Coast Borax Company and Suckow Borax, Consolidated, Limited. In the drilling which followed on this land, sodium borates were found in the No. 1 hole on the Western Borax property on July 4, 1927. The writer owes most of his detailed information about these remarkable deposits to his association with the development of the Western Borax mine.

In September 1927, Dr. Waldemar T. Schaller of the United States Geological Survey visited the Baker mine of the Pacific Coast Borax Company, and later published an elaborate account of the mineralogy of the deposit (Schaller, W. T. 30).

In the meantime a contest had arisen over title to some land including that on which the Western Borax mine was situated, and the writer was called to testify (June 25 to July 3, 1929) as to the nature and origin of these deposits. Dr. F. L. Ransome and Dean F. H. Probert were also engaged in the same case in behalf of the Western Borax Company. The writer was engaged in connection with another case, tried in October 1931, involving the Suckow mine and property, and reviewed the subject on the basis of detailed examinations made in the Suckow mine in September 1931.

Following personal conference with the Director of the United States Geological Survey and subsequent correspondence, a special topographic map of the Kramer borate district was made which was completed in pencil form in June 1932. Although it had been tentatively arranged that the writer was to do the geological work on this map as a base, some

project of a general scope caused the Geological Survey to send a party into the district in the early part of 1934. Results of this work by the Survey became available with the distribution of United States Geological Survey Bulletin No. 871 under the general title *Mineral Resources of the Region Around Boulder Dam,* a copy of which was received by the writer November 12, 1936, presumably the approximate date on which this report was issued. In the meantime the surface geology had been mapped by the writer and his son Hoyt Rodney Gale on the Survey base map, and a more extensive report, completed in February 1936, had been prepared in private interest.

Again, in the Spring of 1938, the subject of the nature and origin of the borate deposits at Kramer was brought up in connection with a contest over title to the so-called Little Placer claim adjacent to the Western Borax mine and was extensively reviewed in court, the writer being called on to testify and be cross-examined concerning his views on the subject. As a result of all of this rather thorough sifting of evidence presented by a number of expert witnesses, the presentation of the writer's views contained herein concerning the origin of the deposits is perhaps essentially a composite of all of the evidence thus far presented and is as near to our present understanding of these matters as it is practicable to state. Much remains that is not yet very clearly understood.

By courtesy of the Pacific Coast Borax Company a single visit was made by the writer to the underground developments of the Baker mine on June 2, 1941, unfortunately without mine maps or opportunity to make many personal notes. Of late years the writer has been engaged with various operators who have drilled exploratory holes in the general vicinity of the main deposit, and a good deal of general information concerning the geology of the district has been developed thereby.

MINERALS IN THE DEPOSIT

The mineralogy of the deposit at Kramer is very completely described by Schaller (30), and the minerals as they are found in the deposit are well illustrated. The materials at Kramer most important for the commercial production of refined borax, boric acid, and other boron-containing products, are the two sodium borate minerals, native borax and kernite.

Native borax (locally called "tincal"), $Na_2B_4O_7.10H_2O$, believed to have been the primary mineral which crystallized out of water solution in bedded layers interstratified with occasional beds of sediment, forms the central massive body of crystalline sodium borate of the deposit at Kramer. It is glassy clear where pure, of massive to granular texture, but is usually somewhat mixed with clayey sediment by which it is more or less clouded. Borax also occurs as a secondary mineral as an alteration of kernite, in large masses without obvious structural form, and in numerous cross-cutting veins in many parts of the deposit. It composes more than half, probably much more than half, of the borates in the Kramer district.

Kernite (also locally known as "rasorite"), $Na_2B_4O_7.4H_2O$, the new mineral first found in the Kramer district about August 14, 1926,[1]

[1] Analysis reported by laboratory of Pacific Coast Borax Company at Wilmington under date of August 18, 1926.

occurs in thick, roughly bedded masses, often as distinct idiomorphic crystals, sometimes of very large size. It is also glassy clear where pure, but like the borax is subject to contamination by included sediment. When kernite is broken it exhibits prominent and characteristic cleavage faces. Kernite and native borax compose the major part of the borates in the Kramer district.

Tincalconite, $Na_2B_4O_7.5H_2O$, although probably not a part of the original deposit underground, occurs as a white powder on surfaces of borax and kernite after they have been exposed to drying atmosphere, both in the mines and after the material has been brought to the surface.

Ulexite, $NaCaB_5O_9.8H_2O$, occurs as a probable primary mineral in nodules or lenticular fibrous aggregates, within the clays that overlie the sodium borate and in a broad zone to the east, west, and to some extent to the north, of the sodium borate deposit. Possibly secondary, or at least of a later order of generation, ulexite appears in veins or veinlets filling fractures either paralleling or cross-cutting the bedding of the other borates and associated sediments. Most of this secondary, vein-form ulexite is of a very dense, hard variety and not like the well known "cottonball" that is commonly found in deposits near the surface. In many veins the ulexite consists of cross-fibered, vein-structured crack fillings and has a rich satiny, almost opalescent luster on fresh fractures.

Probertite (also named "kramerite"), $NaCaB_5O_9.5H_2O$, occurs widely distributed and, in the aggregate, in considerable quantities within the borax and kernite, and in the sediments adjacent to these minerals, apparently chiefly in the environment in which the kernite exists, that is, in the Baker and Western Borax mines. W. T. Schaller first identified as probertite one specimen submitted to him in October 1931 by the writer, who collected it in the Suckow mine in section 14. Schaller later revoked this decision; but Joseph Murdoch (45) has since proved that probertite does occur in the Suckow mine. It consists of needle-like radiating glassy crystals, often found in rosette form.

Colemanite, $Ca_2B_6O_{11}.5H_2O$, occurs in nodular or chunky masses within the gummy bluish clay or shale that overlies, and seems to enclose in lateral extension of, the main sodium borate deposit. It is here entirely similar in occurrence to the other known deposits of colemanite in Tertiary sedimentary beds in the southwestern part of the United States. Occasional distinct veins of colemanite are found, which are assumed to be fissure-filled offshoots from the nodular or lenticular masses. The nodules of colemanite are often geodal, indicating crystallization within a pre-existing cavity, and at places are found in association with ulexite in such way that the colemanite appears to have been derived by alteration from ulexite which formed first in the nodular aggregates, the colemanite taking much the same space that was originally occupied by the ulexite. Colemanite is commonly glassy clear when pure, showing aggregates of short prismatic crystals, but varies to milky white or colored when sediment is included. It usually shows distinct cleavage, somewhat resembling iceland spar or calcite.

Howlite, $4CaO.5B_2O_3.2SiO_2.5H_2O$, was found in one or more thin nodular layers in the "footwall" shale near shaft No. 3 of the Western

Borax mine crosscut on the 950-foot level. This was determined by Dr. Joseph Murdoch from a specimen submitted to him, by refractive index measurements and a micro-chemical test for silicon. This is the first report on record of the occurrence of howlite in the Kramer district.

Realgar, a sulphide of arsenic, occurs as an accessory mineral in these deposits, showing as small red-ink-like splotches in the white kernite, borax, or in the sediments, perhaps only in the areas in which the kernite exists.

Stibnite, a sulphide of antimony, has been reported.

Pyrite(?). A few specks of a yellow sulphide mineral thought to be pyrite were noted in a very hard dense sedimentary bed within the sodium borate mass in the Western Borax mine.

Calcite or *aragonite* (the latter suggested by fluoroscopic tests) has been observed in some places in the sediments associated with the borates, but generally in minor amounts.

Chert, in beds or layers half an inch to several inches in thickness, has been found at various places near the base of the lake-bed shales underlying the borates, generally within a few feet of the top of the underlying basaltic lava.

These minerals occur in a matrix that is principally clay of a somewhat peculiar nature or composition. It is a sediment evidently deposited in water, apparently accumulated in a shallow lake. Such clay is characteristic of almost all borate-mineral occurrences observed by the writer, particularly those of Tertiary age. Dr. Veatch, in a widely quoted letter written in 1857 to California Borax Company, described Borax Lake, one of the best examples of a borax deposit that is apparently forming at times today. Borax Lake (Vonsen and Hanna, 36, pp. 99-108) is a pool in an enclosed basin rimmed by volcanic rock, in a fumarolic area; it is reduced to a marsh-like surface in summer, consisting of soapy mud topped by an incrustation of salt. The so-called blue clay or shale of the Kramer area is apparently similar to this mud. Usually soft and putty-like in moist state as encountered underground, it shrinks and hardens when dried. Generally dense, smooth, and moisture-absorbent, it occasionally includes coarser sediment, even gritty and arkosic beds, particularly near the edges of the borate deposit.

This clay provides an effective seal against migration of ground water, and probably has afforded protection to the borate salts from solution underground. At the Western Borax mine, the main body of sodium borate is capped by a thin layer of dense ("hanging wall") shale; but not far above this stratum of shale is a bed of "quicksand" or loose pebbly sand that carries a considerable flow of water.

SURFACE FEATURES OF THE AREA

To the average visitor or even resident of the desert region, the surface of the country has a noncommital aspect, except for certain features with which familiarity lends understanding. This applies to the geology, physiography, and mineral resources, and it is only by careful analysis that certain fundamental factors involved in their system may be recognized.

The Mojave Desert is a characteristic portion of the western Great Basin province. In contrast to the more mountainous regions to the north and to the south the Mojave is an area of relatively moderate relief, including scattered groups of mountainous masses and broad intermontaine valleys and basins. The sand-and-gravel covered plains that occupy most of the area are mainly the nearly level surfaces of sheetflood alluvial fans that lead down gradually to playas or clay pans in the bottoms of undrained basins. Contrasting steep-sided mountain ranges and groups of hills consist either of lately uplifted fault-blocks or of volcanic or other erosion-resisting masses that have better withstood the long-continued degradation of the areas exposed to these processes.

In this region the mountainous masses consist mostly of old and much eroded rocks which are pre-Tertiary in age. The remnants of these project abruptly through the alluvial slopes of the lower lands, comprising many of the more conspicuous peaks, but the older rocks also underlie, almost at the surface, extensive areas of relatively low rolling upland, where the bed-rock surface is commonly deeply disintegrated by the weathering that has penetrated from exposed surfaces. As indicated in the following discussion, much of this anciently weathered surface on the basement rocks probably dates back in geologic time far beyond the epoch in which the larger irregularities of present topographic forms were produced. All of these pre-Tertiary rocks present a complex of varied types and origin involving an ancient history, and are not much concerned in the present discussion of the borate deposits and the later formations associated with them. The basement complex forms the foundation upon which the Tertiary and later deposits were laid down.

Most of the Tertiary sediments that include the borates are made up of rock or mineral fragments that obviously were derived from disintegration of the basement rocks. The deposits formed during this part of the Tertiary were mostly those of an arid or semiarid region, similar in a general way to the deposits now accumulating in various parts of the desert. Detritus washed from uplifted areas or spread by eruption from volcanic vents accumulated chiefly on the slopes that led down toward the bottoms of the basins then being aggraded. Alluvial deposits ranged in texture from coarse and little-sorted mixtures of sand, gravel, and boulders to the fine clayey sediments that were deposited last in the lower parts of the basin areas. Some of these sediments seem to have accumulated while large areas were flooded, perhaps only temporarily, over a nearly flat land surface. The finest sediment, which collected in still-standing water, formed the clay pans or playa deposits on the intermittently flooded basin bottoms, of which the present-day Rogers or Muroc Dry Lake is a good example.

REGIONAL GEOLOGY

Sequence of Formations

With interest primarily centered on the borate deposits the sequence of geological formations is described herewith in the order in which these beds would normally be found in digging from the surface down; that is, beginning with the youngest formations. This reverses the order in which these geologic units accumulated, and is therefore the reverse of the historical method of treatment.

Any bore hole or other prospect in the Kramer district is likely to encounter the beds here described, either fully developed as indicated in the table of classification which follows, or partly developed where some of the members may be lacking because of non-deposition or removal by erosion during the general period in which the deposits were being formed. It is therefore important to point out the characteristics of each of these units in such way that the identity or classification of beds encountered may be recognized, thus affording a guide for interpretation of further exploratory work in the region.

By reference to the geological map herewith (plate 51) it will be seen that most of the area is covered by alluvium. Underneath this, at depths that vary from place to place, occur the bedded sequence of Tertiary sediments and associated lavas, within the upper part of which the borates are included. These Tertiary rocks lie upon a floor of metamorphic and igneous rocks including the great body of intrusive "granite" (quartz monzonite and related plutonic igneous rocks), here classed together under the designation of pre-Tertiary (basement) complex.

A generalized stratigraphic section of the sediments and lavas that lie upon this basement floor is given below.

General stratigraphic sequence of rocks in the Kramer area

	Approximate maximum thickness (feet)
QUATERNARY	
Recent alluvium—(Stream and flood-plain deposits)	300
Older alluvium—(Bench gravel, sand and boulders)	---
(unconformity)	
TERTIARY	
Ricardo formation—Fanglomerate, including the Kramer lake beds which contain the borates and the Saddleback basalts which underlie the borates	1500
(unconformity)	
Rosamond formation—Fanglomerate, containing clayey sandy, arkosic, and tuffaceous sediments, local deposits of white clay and magnesite; regionally contemporaneous with rhyolite-latite lavas and tuffs spread from vents widely distributed throughout this general region	1500
(major unconformity)	
PRE-TERTIARY (basement) COMPLEX	
Granitoid rock (quartz monzonite and similar plutonic igneous intrusive rocks), and related pegmatite dikes, of supposed late Jurassic age	---
Acid lavas and silicified tuffs, of supposed Jurassic age, older than the granitoid intrusions	---
Schists and related ancient rocks (possibly altered Paleozoic sediments)	---

Quaternary Deposits

Recent Alluvium

Recent alluvial deposits cover the surface of the country in the vicinity of the borate deposits. These consist of relatively unconsolidated accumulations of sand, gravel, and boulders, all more or less embedded in a matrix of clay, in the poorly sorted condition characteristic of deposits left by waters flowing over the land surface. These deposits have been built up over former valley or lowland areas, and now range in thickness from thin edges that lap against the hills bordering the basins of their

accumulation to 250 or 300 feet as recorded from drill holes in the deeper parts of the area. The rocks included in these Quaternary deposits consist chiefly of the water-worn fragments of coarse-grained, gray, biotitic quartz monzonite and the associated pegmatites, such as are extensively exposed over the higher lands adjacent to the borate district. Pebbles or boulders of lavas derived from underlying Tertiary formations are included in these alluvial deposits, together with beds of volcanic ash or tuff, and clay derived from the weathering of the tuffs and other rocks. The overwhelming preponderance of the granitoid materials is due to the great expanse of these plutonic rocks that has been exposed in this area, long subjected to disintegration and erosion, from which the more resistant siliceous portions have been preserved. A fair example of the composition of all of these Quaternary deposits is found in almost any of the alluvial fans whose slopes compose most of the surfaces of the plains in this region now. At present the surface drainage of most of the Kramer district leads down toward the southwest into the large clay pan called Muroc Dry Lake (Rogers Dry Lake), and there are other small pans of the same sort where flood waters are ponded to form intermittent lakes. In not so very ancient Quaternary time the waters of Muroc Lake basin may have overflowed by way of a channel leading through the hills in the western part of the Kramer area, passing between Castle and Desert Buttes into the Fremont Valley. At present there is a broad divide, some 25 feet or so above the general surface level of Muroc Lake, on this route a few miles north of the dry lake.

Older Alluvium

Remnants of an earlier, higher-level stage of alluvial distribution are preserved in the form of terrace deposits. These undoubtedly represent an older Quaternary alluvium distributed during the development of the present topography, while the mountains stood somewhat higher than they do now and the basins were probably somewhat deeper. Thus while the terrace-form remnants are seen around the borders of the Kramer basin, it is to be expected that formerly they extended continuously to levels below the present surface in the deeper parts of the basin. This is suggested by boulder deposits encountered in a shaft and bore hole sunk on the border of the present Kramer basin in the southeast corner of sec. 13, T. 11 N., R. 9 W., S.B., which may have been a channel deposit in the older alluvium, since large stream boulders of this sort are not recorded generally at the base of the Recent alluvium.

Distinction from the Tertiary

Usually it is not easy to distinguish between the unconsolidated deposits of the Quaternary cover and the more consolidated beds of almost exactly the same composition which occur in the upper part of the underlying Tertiary. Theoretically there is a strong unconformity between the two series but this is rarely exposed so that it can be identified as such in place. Where bedding can be distinguished the Quaternary is seen to be in nearly horizontal distribution, the underlying Tertiary having a distinct dip, as recorded in the section exposed in the Suckow Colemanite shaft No. 2 in sec. 22, T. 11 N., R. 8 W., S.B., when it was examined by Dr. L. F. Noble and the writer (Noble, L. F. 26, p. 49).

The base of the looser Quaternary gravels and deposits is at places marked by a layer of lime or ancient caliche, reported from bore holes, where water is likely to be had if any exists at that place, "perched" in

sand or gravel just above this contact. Water troubles encountered in the sinking of mine shafts usually occur at this horizon, although the caliche is not always recorded from such work. In prospecting for buried deposits of the borate minerals the looser deposits have commonly been referred to as the ''overburden'' or ''unconsolidated granitic sediments''; but there has been much uncertainty as to the exact differentiation of the later Quaternary from the Tertiary deposits in the drill records.

Tertiary Deposits

Subdivision of the Tertiary Sequence

Tertiary sediments in this part of the Mojave Desert are mostly alluvial (fanglomerate) deposits, similar in composition and texture to the Quaternary alluvium that covers the surface of plains and valleys in the area at the present time. These deposits include a mixture of generally poorly sorted sediment like the usual type of deposit laid down by intermittent and shifting streams on the surfaces of broad alluvial fans. These are sandy and pebbly beds with a considerable admixture of clay, materials of which have been derived mainly from decomposition of the ancient crystalline rocks of the region together with a considerable amount of volcanic material derived from eruptions that were more or less contemporaneous with the distribution of the sediments. Such beds are subject to great lateral variation. For this reason it has been extremely difficult to make a distinct or hard-and-fast subdivision of the group.

In the present paper this Tertiary sedimentary and volcanic sequence has been divided into two parts. The upper part, here referred to as the Ricardo formation, consists mainly of alluvial fanglomerate deposits but includes the borate-bearing lake beds of the Kramer basin and, closely associated with the borates, an underlying series of flows and lava intrusions which range from olivine basalt to latite. The borates are confined to a restricted area in the Kramer district, obviously to what was formerly the lowest part of that basin, but the non-borate-bearing portion of the lake-bed section is of much wider extent. The basaltic lavas that poured out over the land surface before the borate-bearing lake beds began to accumulate occupy a considerable area in the vicinity of the present Kramer basin, but are also essentially local features, distributed from vents in the Kramer district. The upper division of the Tertiary section, which contains the borate deposits, is therefore a composite section including several relatively distinct members in the Kramer area. The lake-bed section and associated basaltic lavas are the subject of special consideration in the present report.

The lower division of the Kramer Tertiary section is correlated with the Rosamond series of the type locality some 30 miles distant. As in the type locality, the Rosamond contains much alluvial material, of the fanglomerate type, but is characterized especially by contemporaneous eruptive volcanic rocks of types more siliceous than the basalt of the upper division that contains the borates. Beds of white to light grayish volcanic tuff are widely distributed in this lower (Rosamond) division of the Tertiary throughout this part of the Mojave Desert. Clays, limestone, chert, and some magnesite deposits of lakebed or spring-deposit type are characteristic members throughout the region.

Lacustrine deposits are found at various places almost throughout the Tertiary sequence. Being accumulations in local basins, they natur-

ally finger off into land-laid deposits that covered the areas around former lakes or playas. It is probable that intermittent water bodies existed at various places during the Tertiary just as they do at the present time.

The only fossils that have been recorded from the Kramer area are ostracods (found by the writer in some drill cores and at one locality in surface outcrop beds); algal remains or impressions and some fresh-water mollusks (also found by the writer in limestone that occurs in the lower part of the Rosamond formation), water-rounded boulders of silicified wood in a conglomerate channel deposit that lies at the base of the basic lava flows at one locality, and a fossil egg, complete, like a small hen's egg, found embedded in stratified crystalline borax in the Suckow borax mine by miners.

Ricardo Formation

General Features. The stratigraphic section at Ricardo has been given some prominence because of the finding there of numerous vertebrate fossils. Baker (11, pp. 354-357; 12, pp. 123-126) gives the most extensive account of it; and further notes are added by Buwalda in Merriam's paper (Merriam, J. C., 19, pp. 447-449). The section has been loosely correlated with the section first named Rosamond series by Hershey (02). A distinct and scenically attractive rock section crosses a part of Red Rock Canyon a short distance above its mouth and is seen again in Last Chance Gulch somewhat farther to the northeast. Most attention has been paid to the fossil-bearing part, which is mainly the upper part of the section exposed. Throughout this area from Red Rock Canyon to Black Mountain and beyond, the section is divided by two flows of basic lava, both included within a thickness of about 100 feet. These are readily traceable from Red Rock Canyon to Black Mountain and beyond. The section below these lavas consists of pink tuff, coarse pebbly tuffaceous sandstone, and softer beds that are probably also largely tuff, the whole overlying the older crystalline basement rocks which are exposed in the gorge at the lower end of the valley. The section below the basic lava sheets is about 1,500 feet in thickness, and corresponds in a general way with lithology that characterizes the Rosamond series of the type locality. The corresponding section that lies above the basement in the lower part of Last Chance Gulch to the north is much thicker, including conspicuous members of a massive gray sandstone and above that a coarse red sandstone, and silicic volcanic rocks including obsidian, with breccias and tuffs. It appears that there is an unconformity somewhere below the two sheets of basic lavas as the upper section including the lavas cuts in and out upon this lower section. For present purposes it does not seem necessary to discuss details of this lower, more indurated sedimentary section, which is here assumed to correspond to the type Rosamond series.

In the Ricardo area a great thickness of fanglomerate overlies the lavas, including white tuffs and cherty limestones in the lower part near Black Mountain. The name Ricardo can be restricted to include only the lavas and the fossiliferous Tertiary beds that lie above the lavas. The Ricardo, like other continental deposits, is extremely variable in detail in different places. The time which it represents is assumed to be a correlative unit throughout this part of Mojave Desert.

The upper division of the Tertiary, represented by the Ricardo in the Kramer area, is mainly an ancient alluvium (fanglomerate) by which

the land surface was built up in late Tertiary time, but includes also local lake-bed deposits such as in the Kramer basin contain the borates. Interspersed in the lower part of this division at Kramer is a series of basic lava flows and intrusives. Materials of these late Tertiary alluvial deposits range from coarse boulder conglomerate to sandy, pebbly, and finer clayey deposits in a generally poorly assorted composite. Coarser components are chiefly arkosic (derived from the granite or quartz monzonite of the basement) but include rounded fragments of basaltic lava and at places extensive deposits of grayish tuffaceous material. At the base of the section, below the basic lavas, in scattered occurrences, is a conglomeratic layer which seems to mark the unconformable contact with either Rosamond or other parts of the basement complex below.

Within the Ricardo formation as defined for the Kramer borate district alone, are three distinct units or members: (1) the post-borate conglomerate (at the top); below which come (2) the "lake-bed" deposits; and (3) the Saddleback basalts, which form the base on which the borate-bearing lake beds rest directly.

Post-Borate Fanglomerate. In the Kramer district where the borate deposits exist, the first Tertiary beds usually encountered by boring are part of the fanglomerate section which has been referred to above. In the deeper parts of the borate-bearing area a considerable thickness of coarse conglomeratic beds is preserved. At places these conglomerates include boulders of very large size. At the Western Borax mine the No. 1 shaft was sunk through these upper Tertiary conglomerates practically from the surface to the depth of 640 feet, where the lake beds were encountered. At one time during the sinking of this shaft, a rounded boulder of "hard granite" (quartz monzonite) was encountered. This boulder was removed intact by drilling a hole through it and suspending it on the hoist cable, it being so large that it could barely be passed out lengthwise in the 4- by 6-foot shaft. These boulder conglomerates are exposed at the surface on the west side of the Water Tank ridge southwest of the Western Borax mine, particularly near the south end of this ridge.

Though drilling records concerning this part of the stratigraphic section are very imperfect and usually record the formation only as "sand, gravel, boulders, granitic sediments" and the like, descriptions of it have been obtained by observation of shaft sections in the borate-bearing area. Unfortunately most of this type of information has not been available for geologic study. A good exhibit of these deposits was seen by the writer in company with L. F. Noble (May 25, 1924 and December 14, 1924) at the Suckow Colemanite shaft No. 2 in the E½ sec. 22, T. 11 N., R. 8 W., S.B. That section was described by Dr. Noble (26, p. 47, and diagram p. 49). Situated well out within the basin, the conglomerates were not so conspicuous a feature there as elsewhere. The lower part of the section in this shaft was seen to be coarse arkosic sandstone in direct contact with the underlying moist clay-shale that contains the colemanite and ulexite at this place. The contact was considered a normal depositional transition suggesting no marked stratigraphic break or unconformity. The conglomerate phases were described as typical fan conglomerate, and these were interspersed with finer beds composed largely of volcanic ash, having a pale greenish color, often sandy, locally called "the green shale."

One successfully cored hole was drilled by R. L. Triplett for Marshall Bond in the SE¼ sec. 19, T. 11 N., R. 8 W., S.B., several miles west

from the known westerly limit of the borate deposits. Here alluvial deposits very like those that cover the surface were found to extend to the depth of 711 feet. At this depth the top of a bed of black basaltic lava was reached. At the time of the drilling the uppermost 276 feet of loose bouldery alluvium were assigned to the Quaternary. More firmly consolidated material, of essentially the same composition but with a prevailing tan to brown color, extended to a further depth of 300 feet, below which came a section 135 feet thick consisting of finer, more clayey material with a distinct bluish-green color, thought to be correlative with the lake-bed section of the borate area.

Lake Beds, Including the Borates. The sediments which contain the borate minerals consist chiefly of clay and shale with some beds of arkosic sands and conglomerates. They are an ancient playa or lake-bed deposit which was formed in a shallow basin during the latter part of the Tertiary, following the eruption of a series of basaltic lava flows extruded from some nearby vents. The lavas which preceded the lake-bed deposits and included the borates are structurally related to the lake-bed sediments which overlie them and at places can be seen to be distinctly unconformable over the lower series of Tertiary sediments that underlie them. These lake beds and lavas are therefore classed with the overlying upper Tertiary Ricardo formation which, in most places, is mainly fanglomerate. The borate-bearing lake beds and the associated lavas occupy the basal part of the Ricardo in the Kramer borate district.

The surface on which these lake deposits began to accumulate is mainly that formed by the underlying lavas. These sheets of molten lava must have flowed out over a low and nearly horizontal land surface so that water accumulated over the whole area of the borate-bearing playa at the end of the eruptions. The concavity of the basin in which these beds accumulated was probably more a topographic feature than a prior synclinal form. It may be assumed to have been merely a low place on the land surface at the end of the epoch of eruption, but somehow a closed basin was produced that was deep enough to accumulate sediments and borate deposits to a thickness of several hundred feet.

The lake beds are dominantly soft and easily eroded and have been preserved in the present basin which was structurally produced, mainly by post-borate deformation. The present basin accords approximately but not exactly with the basin in which the lake beds were originally laid down. This can be shown by comparing known thicknesses of the deposits as indicated by mining and bore holes with the present position of these beds as shown by the structural mapping.

The known area occupied by the borates extends from near the northeast corner of sec. 21, T. 11 N., R. 8 W., S.B., on the west to the southeast part of sec. 18, T. 11 N., R. 7 W., S.B., on the east, a distance of about 4 miles. From north to south the deposit is known to extend from about the middle of section 13 to just south of the center of sec. 24, T. 11 N., R. 8 W., S.B., about 1 mile at the widest part. The whole deposit occupies a roughly oval-shaped area. The Tertiary beds that contain the borates lie in the form of a somewhat irregular synclinal basin, the lavas that underlie the borates and portions of the older basement rocks rising to outcrop around the borders of the basin on all sides except on the southwest. As exposed in the mines, the borate beds are both gently tilted and folded into broad arches. The resulting dips are commonly as much as 10 or 15 degrees from the horizontal attitude of the original bedding.

Minor faulting in these beds is fairly common, as shown by underground development. A consistent system of northwest-trending faults that offset the borate beds and underlying lavas (as well as the older rocks) traverses the whole district, and is obvious in major features in this part of the Mojave region. Faulting of this system may be seen in detail on the surface in outcrops of lava on the low hill in the NW$\frac{1}{4}$ sec. 13, T. 11 N., R. 8 W., S.B., northwest of the Baker mine and northeast of the Suckow Borax mine, and at other places in the Kramer district. Faulting of this trend is an important feature in the Baker mine where it marks both the northeasterly and southwesterly limits of development. It was this abrupt termination of the main sodium borate ore body that led C. M. Rasor, field engineer for the Pacific Coast Borax Company to describe the deposit as ''shaped like the back of a desert turtle,'' emphasizing the abrupt turn-down of the deposit on these sides. The sodium borate deposit has now been found in extension of the area of the original mine developments, offset down on both sides. Both of these major faults and some minor faults of the same system are now clearly recognizable in the mine.

The abrupt termination of the deposit on the south side of the basin—near the Western Borax mine—has been assumed to be due to faulting, by which the hills to the south of the basin were uplifted, perhaps in pre-borate time. It is an hypothesis of H. R. Gale that this fault is of the overthrust type, with uplift and thrust from the south toward the basin on the north. A distinct change of formation from north to south along the immediate front of the hills is shown by the surface geology and confirmed by a number of drill holes that have been sunk along this line.

The lake-bed section is divisible into three parts. At the top is commonly found a thickness of 30 to 50 feet of greenish micaceous shale, usually thin-bedded but not notably laminated. This does not contain borates. Below the ''green shale,'' in the central or main borate-bearing part of the district, comes the more distinctively clayey part of the deposit, usually finely laminated, which contains most of the borates. This has been locally referred to as the ''blue shale or clay'' although it contains some coarser sediment as well as the various classes of borate minerals. Including the massive body of crystalline sodium borate that exists in the central part of the borate area, this unit has a thickness of 200 to 250 feet. The ''blue shale'' grades down into a lower unit known as the ''footwall shale'' of the borate mines, which is generally a dark greenish to black slaty shale, containing seams or veinlets of ulexite and probertite. This ranges from about 30 to 50 feet in thickness. At the base it rests directly on the top of the basaltic lava where that is present.

The ''green shale'' at the top of the lake-bed section was probably deposited in standing water because it is generally fairly evenly bedded, but it is not laminated as is the underlying ''blue shale.'' It is composed of arkosic constituents mingled with volcanic tuff derived from older Tertiary deposits such as occur in the vicinity. It is similar to beds that are found by drilling between the several basaltic lava flows of the section that underlies the lake beds of the borate section. It is probably best described as sandy clay shale. No borates have been found in this part of the section.

The so-called blue shale is characteristically a fine-grained, soft, dark-colored, putty-like material, such as is generally associated with borate minerals, both in the Kramer and in other borate districts. Underground it is dark bluish to gray in color, but when dried by exposure to

the air it shrinks and becomes a light-gray hard mud or clay. Its dark color when fresh may be due to organic matter included, as this clay seems to partake somewhat of the characteristics of a lake-bottom ooze. This material has been referred to as a colloidal mud because it absorbs and retains water with much swelling to a putty-like consistency, as when it is encountered in mining or drilling. Although massive and compact it is commonly bedded in minute lamination, indicating that it was laid down in relatively quiet standing water.

In many places, particularly in association with the kernite and probertite of the borax mines, this shale is considerably indurated, possibly by secondary alteration. However, this clay and the borates associated with it, very commonly include interbands of sediments ranging from arkosic sands to conglomerates. From these and the way in which these interbands seem to finger into the clay and borate deposits, especially around the borders of the deposit, it is assumed that still-water deposition in the central basin area was at times interrupted by overwash of surface waters carrying sediment from adjoining land slopes. One of these thin beds of sediment interstratified with the borax in the Suckow mine was found carrying well-defined ripple marks. They were of the parallel rib type suggesting wave action on the bottom of a body of shallow water.

The sodium borates constitute the largest and most distinct individual member of the deposit, and this has locally been referred to as "the crystal body." This massive body of crystalline borate salts now exists only underneath the surface of the ground, mainly at depths ranging from some 300 feet in the Suckow mine in sec. 14 to more than 1000 feet at places on the Western Borax or adjacent property. The calcium borate minerals extend beyond the sodium borate body, occupying a zone peripheral to the sodium borate deposit, and also occupying beds which overlie the sodium borate.

The "blue shale" of the borate-bearing part of the Kramer basin, either above the sodium borate or throughout the area beyond the limits of the sodium borate mass, characteristically includes nodules and lumps of the lime or calcium borate minerals colemanite and ulexite, scattered irregularly in aggregates throughout. Of these two minerals colemanite usually predominates in the lumps or nodules, and ulexite is conspicuous in the form of crack fillings or veinlets. The lumps show some conformity to the bedding of the sediment, but the colemanite masses as a whole thicken or pinch off suddenly when traced laterally. The colemanite usually shows glassy to milky white, with prominent cleavage resembling calcite in a general way, while the ulexite is white with a fibrous texture.

The nodular deposits of colemanite and ulexite embedded in soft "blue shale" or clay as a matrix are similar in almost all respects to the borate deposits in Tertiary formations found in other districts. This includes the deposits on Furnace Creek in the Death Valley region, those in the Calico Mountains north of Daggett, and in the Lockwood Valley district in Ventura County. It is likely that these deposits in Tertiary beds were formed under essentially similar physical conditions, but it is not certain that they are all of exactly the same geologic age.

It has already been noted that the first borate mineral found in the Kramer district was colemanite encountered by chance in a well that was being drilled for water. This was at a location near the center of the NW¼ sec. 22, T. 11 N., R. 8 W., S.B. The first borate mined and shipped

from the Kramer district (in 1924) was colemanite obtained through a shaft and small mine opened near the middle of the south side of the northeast quarter of this same section 22. Both of these locations lie outside the limits of the sodium borate deposits described above. The calcium borate minerals are distributed in a larger area than the sodium borate. The central area that contains mainly the massive tabular body of crystalline sodium borate is almost surrounded by a peripheral zone that contains only the calcium borate minerals colemanite and ulexite. The borates are rarely exposed at the surface but ulexite in clay of the borate-bearing section is obscurely exposed on the point of a little ridge in the SE$\frac{1}{4}$ sec. 18, T. 11 N., R. 7 W., S.B., where the borate beds are uplifted along a fault.

The zone containing calcium borates bordering the main deposit of sodium borate may be an extension of the ''blue shale'' zone containing the calcium borates that overlies the sodium borate deposit; or it is possible that it is in part a fine alluvial deposit that was laid down on the lower slopes bordering the main deposit while sodium borate was being deposited in the central basin area. An outline of the area known to contain borates of all classes, both sodium borate and the borates containing calcium, is shown on the general geologic map included herewith. This is roughly oval in form, and about 4 miles in length from east to west and 1 mile from north to south at its widest part.

The great body of crystalline sodium borate for which the Kramer district is now renowned lies within the lake beds described above as ''blue shale.'' Originally deposited in water, by crystallization out of solution as borax, it was laid down in bedded layers more or less interstratified with sediment, including some sediment mixed with the crystalline borax. This immense deposit of crystalline sodium borate is, however, remarkably pure except for a cloudy mixture of sediment in parts and the interbands referred to above. The original borax has been partly changed to the mineral kernite, which is also a sodium borate, containing less water of crystallization than borax. Sodium borate is practically the only saline substance in the deposit. Almost none of the common constituents of desert saline accumulations, such as chlorides, carbonates, bicarbonates or sulphates of sodium, or other bases are included. Ulexite and probertite, borates of calcium and sodium, occur within the sodium borate deposit, but in relatively minor proportions. Small spots of red-ink-colored realgar are scattered throughout the parts of the deposit that include the kernite and probertite, and this is about the only accessory mineral to be seen within the sodium borate beds. Stibnite has been reported in minute amounts but has not been seen by the writer.

Insofar as the area underlain by the deposit of sodium borate has now been determined, it has a roughly triangular outline, the corners being marked approximately by the three mines, the Baker, the Suckow and the Western Borax. This covers an area about a mile and a half long from east to west and a little more than half a mile broad. This mass of sodium borates has the general tabular form of an interbedded member of the Tertiary lake-bed sequence thinning and interfingering with the sediments around the borders of the deposit. In places on these borders the sodium borate pinches down rather abruptly. This abrupt termination of the deposit is explained in part by the manner in which the borax accumulated in the lake water layer by layer, extending to a lake margin that for certain periods of time apparently remained fairly constant in

position as the surface and borax deposit gradually built up. In other places, the boundary limits of the ore bodies as seen in the mines is due to faulting which has offset the original borate deposit, steplike, up or down along certain lines.

The thickness of the sodium borate, including those beds of sediment that are included within the deposit, is known only from mine developments and from bore holes. At the Suckow mine an over-all thickness including three beds of borax and two interstratified units of shale penetrated by the No. 1 shaft is 86 feet. These beds of shale are 10 and 20 feet in thickness respectively. The main unit of the sodium borate deposit is 31 feet thick where it is penetrated at this shaft. At the Baker mine the thickness of the section containing the sodium borate deposits has been reported as ranging from 85 to 114 feet (Schaller, W. T. 36, p. 102). At the Western Borax mine the thickness of the main deposit ranges from about 60 feet throughout the western half of the mine developments to a maximum of about 110 feet in the eastern half, pinching down rather abruptly at the eastern end where there are indications of faulting. Similar abrupt cut-offs occur at both the eastern and western limits of development in the Baker mine, where it is obvious that the deposit has been stepped down on both sides by faulting.

Data concerning the extent and thickness of the sodium borate existing between the three mines are not available, but fairly reliable rumor has it that the sodium borate deposit is continuous, except for displacement by faults, across the basin between these mines, in greatly extended thickness of borate in some part near the center of the sodium borate area. A great body of borax containing some 226 feet of borax in a total of 240 feet, including a thin bed of kernite in the lower part, is said to have been revealed by recent drilling in the north-central part of the basin. The deposit may be even thicker than this as the area has not been very completely explored.

The area which may be said with some confidence to be underlain by the main mass of crystalline sodium borate, as outlined on the map (pl. 51), is about 500 acres in extent. Known thicknesses in various parts of this deposit are about 56 feet at the Suckow mine (including the 3 beds at that place) ; 85 to 110 feet (reported) in the Baker mine; and 60 to 110 feet in the Western mine. There is at least one reported section of 226 feet of borax in the area between these three places. An over-all average of 75 feet thickness of nearly pure sodium borate seems a reasonably conservative estimate.

Tonnage calculations much discussed with reference to the Suckow mine were based on a factor of 113 pounds per cubic foot of borate as it exists in the ground. This is equivalent to about 2,460 short tons of borax per acre per foot thickness of the bed. At this rate 500 acres with an average of 75 feet in thickness would contain 92,250,000 short tons of borax. Not all of such a deposit would be recoverable by mining, perhaps no more than half, and a certain allowance should be made for sediment included in the crude ore.

Footwall Shale. The lower division of the lake beds, which lies between the sodium borate and the top of the underlying balsaltic lava in most of the area in which the sodium borate is present, is a section of dark greenish to gray or almost black slaty shale, ranging from about 25 to 50 feet in thickness. Schaller (36, p. 101) cites a minimum of 7 feet

and a maximum of 55 feet. Locally this division includes some sandstone and coarser arkosic conglomerate, the latter at the south edge of the basin below the ore body of the Western Borax mine. This section is described in various drill-hole logs as "hard slaty shale containing ulexite." This is the "footwall shale" of the mines.

As seen in some of the better cored sections (notably in sec. 18, T. 11 N., R. 7 W., S.B.), this basal shale seems to lie with a normal depositional contact upon the upper surface of the lava, the transition being made up of a thin layer of dark scoriaceous material, evidently derived from the underlying lava, and deposited with the lake beds. At places this basal bed contains some conglomerate but this is not a conspicuous member. Within a few feet above the contact in sec. 18 comes an apple-green siliceous shale, finely laminated, with wavy and contorted bedding. This suggests colloidal silica deposited in shallow water at the edge of the basin shortly after consolidation of the underlying lava. Some of this green shale in sec. 18 contains ostracods, indicating that the water at this place was not too warm to sustain organic life. A few feet above the contact with the lava several thin beds of hard, dense, dark-colored chert, evidently water-laid, one-half inch to several inches in thickness, were found in the drill holes in sec. 18. These are reported to be fairly constant features at this horizon in various parts of the mining area. Fine-grained, creamy colored, "fresh-water" limestone was also encountered in this part of the section. Ulexite in irregular patches suggests that some of the mineral had begun to crystallize during very early stages of lake-bed sedimentation around this edge of the basin. These features mark the beginning of the lake-bed deposits, and are suggestive of a possible entry of magmatic waters following the active eruptive phase of nearby volcanoes or extrusions.

A small area of greenish sediments, evidently part of this basal lake-bed section, outcrops in the northeastern part of the NW$\frac{1}{4}$ sec. 13, T. 11 N., R. 8 W., S.B., just northwest of the Baker mine. Almost all knowledge of these lake sediments is obtained from cores or cuttings from drill holes or from what can be seen underground in the mines.

The footwall shale is exposed at various places in the Western Borax mine. It was first seen at the main station on the 856-foot level of Shaft No. 1, and along the first 100 feet of the main crosscut tunnel that leads from this shaft station into the mine. Here the section is made up of soft, dull-gray, thinly laminated or bedded shale. It is very clayey in composition and distinctly micaceous. It is traversed by innumerable lighter-colored seams, some of which are interbedded layers, but the majority are veinlets of a dense, fibrous, pearly white form of ulexite that is common throughout the mines. At the shaft station some of these seams are grayish-white, more or less structureless, compact, almost granular-looking; these are found to be mostly probertite, possibly an alteration from ulexite. The log of drill hole No. 2, which passes through the main ore body in the Western Borax mine, records a thickness of 32 feet for the footwall shale, underlain by "blue sand" and other sediments which are now interpreted as the coarse dark sandstone and conglomerate found at the foot of the No. 3 shaft. So far as known, this is the only part of the borate basin in which the lava is not found immediately below the footwall shale.

This lower part of the lake-bed section is also well exposed in the crosscut tunnel that extends from the No. 3 winze to the foot of the No. 3

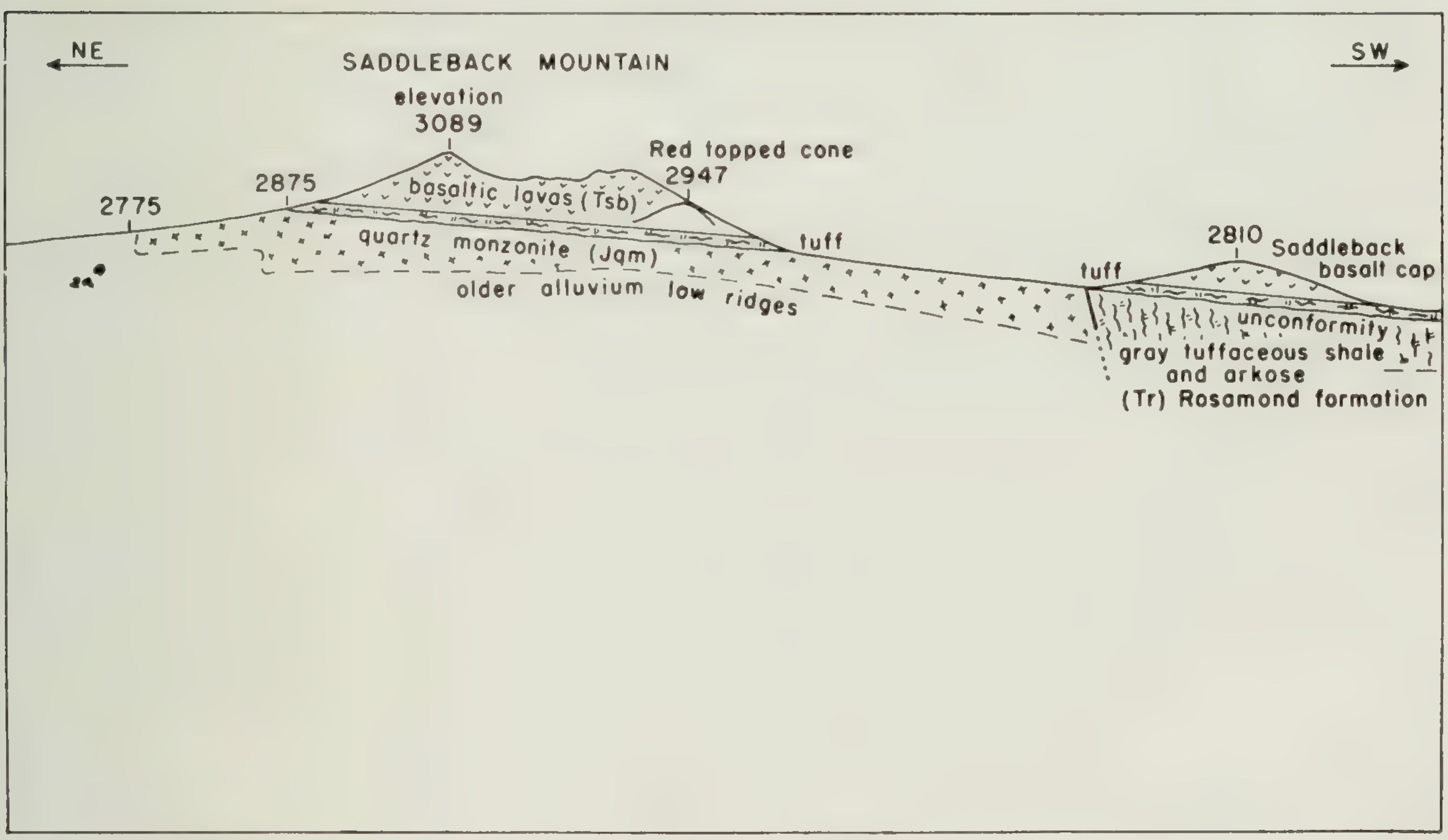
shaft, on the 955-foot level. Here, in addition to the numerous veinlets of hard ulexite, were some streaks of a pure white, hard, almost porcelain-like mineral that proved to be howlite. This is the first report of the occurrence of this mineral from the Kramer district.

Saddleback Basalt. To the north, northeast, and northwest of the plains that occupy the middle of the Kramer borate district, the first ridges that rise out of the alluvium are the outcrops of basaltic lavas that underlie the borate-bearing lake-bed section. These beds of flow lavas dip in general toward the basin in which the borate deposits lie.

The most conspicuous of the summits on which these lavas are exposed is the double top of Saddleback Mountain, which rises about 600 feet above the general level of the plains about its foot, several miles to the north of east from the borax mines. Two sheets of massive, black-weathered lava separated by a zone of reddened arkosic sediment lie in tilted succession across the two summits, the upturned edge of the upper lava making the south summit and a lower sheet similarly forming the north summit. These three units can be traced across the alluvium-filled gap northwest of Saddleback Mountain for a distance of a mile or more and are suggested in an exposed sequence of lavas in the southeast corner of sec. 11, T. 11 N., R. 8 W., S.B., about 1 mile north from the Suckow Borax mine. The identity of individual lava beds is not clearly traceable throughout the area to the west from the Suckow mine, but a series of flows of general composition and structure similar to those at Saddleback Mountain outlines the northern half of the Kramer borate basin. All of these lavas of composition essentially similar to the lava that immediately underlies the borates are included under the designation of Saddleback basalts.

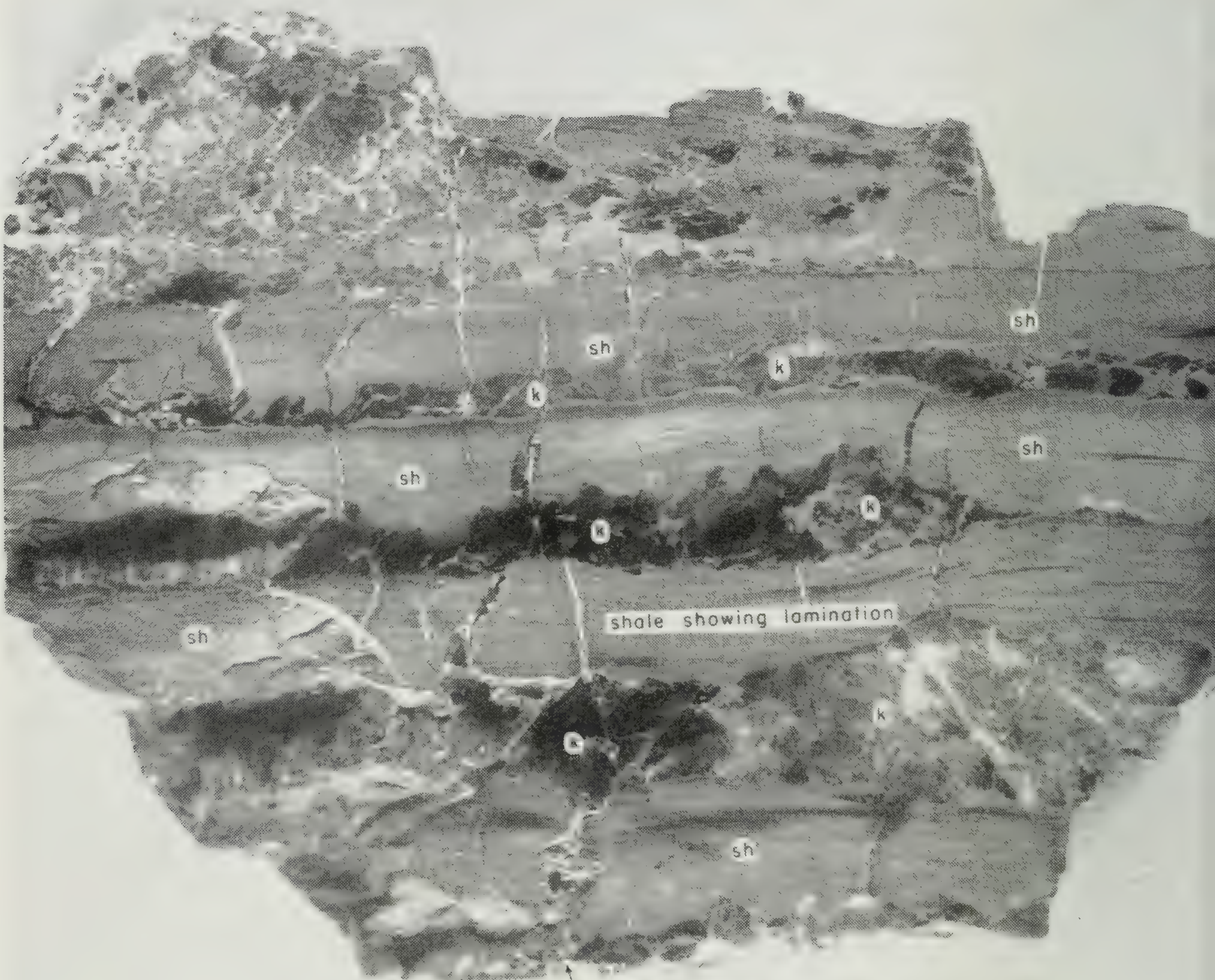
At least three flows of this dark basic lava can be recognized in many sections, being separated by alluvial sedimentary deposits that are much like those that overlie the borate-bearing lacustrine beds. The base of the lowest flow of basaltic lava is usually taken as the base of the Saddleback unit, but a thin section of gray tuffaceous sediment and a basal conglomerate underlie the lava at two significant localities and possibly elsewhere, and this probably belongs to the Saddleback section. On the flanks of Saddleback Mountain the basement of massive granitic rock occupies the lower half of the slope in practical continuity all of the way around the mountain, the granite being cut off on an even plane at the top, this surface being a remnant of the old erosion surface upon which the Saddleback beds were deposited. Viewed from a short distance, a light-gray band may be distinguished almost encircling the mountain, granite below and dark-colored lava above, the contact exhibiting the present dip of about $4\frac{1}{2}$ degrees toward the southwest. The gray band consists of about 25 feet of gray, ashy volcanic tuff, water-deposited, evidently derived by reworking from Rosamond beds elsewhere. The uniformity of this bed indicates that the surface on which it was deposited must have been very flat. At the bottom of this layer is an irregular deposit of coarse grit and conglomerate including fragments of gray ash, and in places granitic detritus. Thus it appears that the erosion that preceded the deposition of this portion of the Saddleback beds, including the Saddleback lava flows, had stripped whatever Rosamond formation there may have been on this part of the Saddleback block before the lava flows were distributed. However, a tilted Rosamond section comes in nearby, truncated and unconformably overlapped by the Saddleback beds.

A, SADDLEBACK MOUNTAIN, VIEWED FROM NORTHWEST



B, GEOLOGIC SECTION THROUGH SADDLEBACK MOUNTAIN

As seen in the above photograph, in strike with contact of basement quartz monzonite and steeply tilted Rosamond tuffs and arkosic beds; shows unconformable cap of Saddleback basalt with tuffaceous layer at base.



TYPICAL SPECIMEN FROM KERNITE DEPOSIT

Showing relationship of shale and kernite ; vertical cut across bedding, showing continous crystallization of kernite in bedding and cross-fractures in the shale

Elsewhere this contact zone at the base of the Saddleback lavas, marking the eroded surface of the top of the underlying granitic basement rock, is revealed in excellent exposures along the north side of the 2647-foot hill (United States Geological Survey topographic sheet) in the northern part of sec. 4, T. 11 N., R. 8 W., S.B. Here a thin layer of soft gray tuff marks the contact and is overlain by a bed of smoothly rounded stream cobbles, rocks of the latter being diverse and including representatives of only the hardest and most resistant materials derived from older formations, perhaps at some distance from the Kramer area. Rounded pieces of silicified wood are included. No basalt was seen in the mixture. Fossil wood occurs in place in gray tuffs of Rosamond type in the vicinity of Black Mountain near Ricardo, suggesting that some of this material may have been derived by erosion from the Rosamond formation. Tilt of the Saddleback beds at this place is about 3° S., due to post-Saddleback deformation such as produced the present structural form of the Kramer borate-bearing basin. The dark-weathering gray basalt that overlies this basal conglomerate and makes up the rest of the interval to the top of the hill represents a thickness of 140 feet of the basaltic lava beds preserved at this place.

The total thickness of the Saddleback lavas and associated sediments amounts to some 600 feet in the thicker exposed sections. Individual flows range up to a thickness of 200 feet reported from at least one drill hole (without allowance for dip) but outcrop sections suggest that the flows are generally thinner than this. The lava is relatively hard to penetrate by drilling and exploratory holes are usually discontinued after sufficient depth in the first solid basalt has been attained to assure that it is rock in place. At places lava boulders included in alluvial deposits may have been mistaken for a lava flow in place.

The section of Saddleback lavas that might be encountered in a deep hole drilled in the vicinity of the borax mines is suggested by the composite built up by means of the profile cross-section as shown on plate 52. This is constructed on the line extending from near the southeast corner of sec. 11, T. 11 N., R. 8 W., S.B., in a southeasterly direction through the borax deposit of the Baker mine. Correlations indicated are probably spaced closely enough to be safe, but individual lava sheets, which seem to have been poured out over a slightly irregular surface, vary from place to place. There is some evidence that the lava flows may have advanced at some places in the form of tongues following shallow valleys. Although the lava is found below the borate beds in almost all parts of the Kramer basin, it does not seem to be present in a relatively narrow belt along the southern margin of the deposit as a whole, notably under the Western Borax mine. The position in which the lava would be expected is occupied by granitic arkose and conglomerate in alternation with gray sand and silt with ripple-marked bedding, suggesting stream deposits which might have been a portion of a fan slope developed at the foot of the hills to the south, as it contains the granite and dark micaceous and schistose components that outcrop nearby in that direction. This is undoubtedly the "blue sand" that was noted in some of the Western Borax drill-hole logs from below the borate beds.

The lavas apparently issued through fissure vents, some of which are revealed by dikes of basalt that cut the Rosamond sediments and join the near-horizontal flow masses of Saddleback lavas in the southern

part of sec. 5 and SE$\frac{1}{4}$ sec. 6, T 11 N., R. 7 W., S.B., about 2 miles northwest from Saddleback Mountain. A mass of basalt, in jumbled bedding, forms the conical hill near the southwestern corner of sec. 10, T. 11 N., R. 8 W., S.B., about 2 miles northwest from the Suckow Borax mine, which may have been one of the intrusive necks through which the basalt rose to the surface. The Stone House Hills in sections 7, 8, and adjacent corners of sections 17 and 18, T. 11 N., R. 8 W., S.B., are one of the most extensive areas of basic lava exposed in the Kramer district. This area of outcrops is limited on the north by a fairly straight line of contact with underlying older Tertiary sediments, supposed to mark the unconformity between the underlying sediments and Saddleback lavas and tuffs above. The lavas in these hills exhibit an alternation of massive sheets of lava and intervals of light-gray tuff, all with a general southerly to southwesterly dip into the Kramer basin. The section of lavas appears to be thicker than it is, as it is repeated in part by at least one clearly defined east-trending fault, shown on the areal geologic map near the north boundaries of sections 17 and 18; and there may be others. Two little cross-faults make minor offsets in the basal contact of these lavas along the north front of the hills near the Stone House. An upper member of the Saddleback series, forming little hills separated from the main mass of the hills (SW$\frac{1}{4}$ sec. 7, SE$\frac{1}{4}$ sec. 18, and center of sec. 16) is interpreted as being the flow that lies next below the borate-bearing lake-bed section or its extension beyond the area that contains the borates.

Erosion remnants of basaltic lava sheets cap the hills in a broad zone around the northwestern border of the Kramer basin, extending from the clay-mine hill in the southeast corner of section 3, T. 11 N., R. 9 W., S.B., to section 21 of the same township. Source of these flows is not clear, nor the reason why these exposures cut off along a distinct line on the south.

The lava that caps Saddleback Mountain is a holocrystalline olivine basalt with texture that is almost diabasic. The texture suggests that some of this lava may be intrusive or at least close to some of the vents from which the lava was extruded, but perhaps the crystallinity of the lava at these places is coarse because of the considerable thickness of the flows. Thin-sections made from the lava at this locality were kindly examined by Professor John E. Wolff, who identified the feldspar phenocrysts as basic labradorite, and the groundmass as an intergrowth of the same feldspar and abundant small granular crystals of augite and olivine. On the surface the olivine is commonly decomposed, leaving little cavities containing a rusty reddish-brown residue, which is probably the source of the rusty weathered colors exhibited by the surface of the rock on exposed surfaces.

Of 13 thin-sections cut from rocks of the Saddleback series of flows or intrusives, 12 were similar to that described above except for some variation of texture, but one collected from the summit of the ridge in the northwest corner of sec. 17, T. 11 N., R. 8 W., S.B., just south of the trace of the east-trending fault, proved to be slightly more siliceous than the rest, and Professor Wolff decided to call it an augite latite, as it is similar to massive flows that occur on the western slope of the Sierra Nevada in the Stanislaus River region. This is a platy, brick-red weathering lava, brighter colored than most of the rock around Saddleback Mountain, mottled gray to brownish, fine glassy looking on fracture, and showing some flow-structure. This is the uppermost sheet of the massive flow section in the Stone House Hills; it is succeeded by an interval of

some 500 feet of soft tuffaceous beds and then the single upper sheet of black-weathered basalt that forms the rim of little outlying hills to the south of the main mass of the hills.

Much of the sediments included between the flows of the Saddleback basalts is composed of gray tuffaceous material, recorded as ''green shale'' in well logs, with—at places—''a trace of borates.'' This means that the samples yielded the green-flame test for boron. Ulexite is reported in minor quantities at various places in the basalt. There is no reason why borates should not be found at places in these lower members of the section that underlies the main borate deposits.

Extensive flows of relatively thin sheets of lava which spread over the surface during Saddleback lava time, as well as even more extensively distributed units of thin-bedded tuffaceous shale (and locally lake-bed clays), show that the land surface was low throughout much of the Kramer area at this time, although some residual peaks or ridges of the more resistant rocks undoubtedly remained above the general level. This was the setting that immediately preceded the establishment of the lake-bed stage in which the borates were to be accumulated. The present tilting and occasional faulting shown by the Saddleback lavas as well as the overlying borate-bearing beds is due to post-borate deformation, and it is this deformation that has produced most of the steep dips and the deep trough close to the southern edge of the Kramer basin as it stands today. Structure contours shown on the two maps given herewith are an approximation of the top surface of these lavas as it would show if all beds above the lavas were removed. The contours represent the depth to which it might be necessary to go in order to penetrate all of the borate-bearing lake-bed section in its present structural position.

In the hilly area between North Muroc store and the clay mine, basic lavas are exposed in patchy areas, mostly on the hills, these being portions of flows more resistant to erosion than the rest, which protect the underlying tuffs, representing a broad western margin of the borate basin. The lava is similar in general appearance to that of the Stone House Hills, which is described as latite, dark in color on fracture and almost vitreous in appearance, reddish-brown on exposed surfaces, breaking into chippy or slabby talus, the larger pieces ringing bell-like on being struck. No thin-section from this area was examined for the present work, but the lava contains many of the little scattered cavities containing rusty red decomposition products believed to have been olivine, and so resembles the basalts of the region.

Throughout the hills south of the clay mine two sheets of lava can be traced, the one about 250 feet stratigraphically above the other, these being included in a section that is mainly light-gray-weathering tuffaceous shale with some arkosic sandstone. These sheets outline a broad anticline or domal structure centering about 1½ miles south of the clay mine. On the crest of this dome a very coarse boulder conglomerate, made up mostly of granitic blocks, is exposed both on the east and west sides of the clay mine road. This may be a channel deposit on the horizon of the base of the basic lava section, and if so it is a marker of the top of the underlying Rosamond division of the Tertiary at this place. One of the drill holes put down about 1,000 feet west of the Leopold camp to the reported depth of 710 feet, is said to have penetrated shaly (tuffaceous) beds all the way down, starting below the lower of the two basic lava sheets, and so presumably passing into the lower division of the Tertiary.

The slight difference in general aspect of the lavas around Saddleback Mountain and those of the main Stone House Hills group and farther west suggests that there may have been two groups of extrusives at about this time, the one at the eastern side of the Kramer basin and the other covering the western part of the area. The inner line of lava hills that extends west from the Saddleback area is essentially of the Saddleback type of lava, and as this seems to be the upper flow sheet of the series it is assumed to be the flow that immediately underlies the borate-bearing lake beds.

A lower portion of the Saddleback lava section is revealed in a well drilled by Russell and Crites in the SE$\frac{1}{4}$ sec. 11, T. 11 N., R. 8 W., S.B., just north of the line of outcrops of these lavas that rises just north of the borax mines. The Russell hole penetrated 230 feet of solid black lava below an upper section of tuffaceous shale. The presence of a lower lava along this line is confirmed by the log of hole No. 65, similarly placed with reference to the lava outcrops, which passed through 126 feet of basalt underground. It seems strange that such a heavy mass of lava has no outcrop in the plain to the north, but this may be explained by the fact that similar lava is reported at somewhat greater depths still farther north (at the water wells in the southwest corner of sec. 2, T. 11 N., R. 8 W., S.B.), suggesting a shallow synclinal basin.

Basaltic lavas correlated with the Saddleback group appear in the hills in sections 15, 20, 21, 27, 28, and the northern parts of sections 33 and 34, T. 32 S., R. 40 E., M.D. As described by H. R. Gale, the section of lavas is thin in this area, estimated at about 50 feet in all. One flow, or in some places two, separated by white tuff, caps some of the hills in this area and at places is seen to overlie an older Tertiary section including acid lava and breccia. The tops of these hills carry a covering of terrace-like conglomerate containing boulders of basalt. Below the basalt flows are white pumiceous tuffs or ash beds, which vary from fine-grained, clayey material to pumiceous sandstones. These beds may be set down by faulting on the southwest front of the hills, and may be the same that are found at the water wells in section 2.

Rosamond Formation (Restricted)

Distinction and Age. A lower division of the Tertiary series (here referred to as the Rosamond formation) is distinctly recognizable in the Kramer area. On the whole, its rocks are more indurated than the clays and shales of the overlying Ricardo or borate-bearing division of that area. The beds of the lower division are generally much more deformed than those of the borate-bearing section. After deformation, these Tertiary rocks, together with the older formations on which they rest, were subjected to extensive erosion, as shown in many places by a distinct unconformity between the borate-bearing beds and these older rocks.

This lower division of the Tertiary consists largely of arkosic sandstone and conglomerate interstratified with bodies of shale or tuff. Lavas and allied products from volcanic eruptions which have occurred in the vicinity locally form a prominent component of this part of the Tertiary succession. These are represented in the Kramer district mostly in the forms of agglomerate and tuff. The volcanic rocks of the Rosamond belong to types more siliceous than the basalts associated with the borates.

White to gray tuffaceous beds are conspicuous features, and these merge into greenish clayey shales. Some beds of massive limestone and dense chert serve at many places to distinguish the lower part of the section, and these are associated with playa-type deposits containing fine white clay at the Muroc clay mine and magnesite at the deposit near Bissell.

The rocks lying above the granitic and other pre-Tertiary basement in this part of the Mojave Desert correspond very closely with the section described as the Rosamond series by Hershey (02, pp. 365-372), with which there is a fairly direct tie by recognition from one locality to the next of distinctive beds or members that correspond and may be adopted as markers. Volcanic eruption burst into violent activity almost with the beginning of accumulation of Tertiary sediments in this region, erupting lavas which range in composition from rhyolite to dacite or latite and possibly also andesite. Basalt is reported with the Rosamond section at the type locality, but at least part of it is intrusive into the Rosamond section and may belong to a post-Rosamond age.

The term Rosamond has been rather loosely used but, so far as known to the writer, no fossils have been found in the beds strictly equivalent to the Rosamond type section, and its age is herewith inferred mainly from tracing types of volcanics associated with sediments occupying the stratigraphic position indicating Rosamond age. These appear from place to place throughout the area around Rosamond, Kramer, and Randsburg, as also in a very much more extensive area. Westward from Rosamond the lavas appear at intervals in the Antelope Valley as far as the San Andreas rift zone, and thence northwestward toward the colemanite deposits in the Lockwood Valley of northeastern Ventura County, approaching the marine stratigraphic section of the southern border of San Joaquin Valley. From this tie to the marine section the age of the Rosamond appears to correspond approximately to the Temblor-middle Miocene of the San Joaquin Valley and elsewhere, more specifically to the Saucesian of marine microfaunal analyses, a division which began with essentially non-volcanic rocks and included the more siliceous types of volcanic rocks in its upper part.

Kleinpell (38, p. 115) states that "Acidic volcanic material occurs abundantly in the middle and upper Saucesian of the southeastern San Joaquin Valley * * * Andesitic flows * * * from the San Emigdio foothills [and elsewhere] may be of Saucesian age"; and (pp. 158-159) "Basaltic lavas are concentrated in the [subsequent] Relizian and Luisian and particularly large quantities of basalt appear to have been extruded at about the end of the Relizian age."

This is at present a slender clue but it seems to be about the most direct tie to the well-established time scale of the California coastal areas. Various other ties leading to approximately the same conclusion could be suggested in a fuller discussion of this subject.

Representative Exposures. Outcrops of the Rosamond formation are found in various parts of the Kramer district but are usually inconspicuous because the rocks are dominantly soft and appear only near ridges made by some resistant members. In many sections seen in exposures, the beds of this division have relatively steep dips, which structure often serves to distinguish them from the more moderately deformed borate-bearing section, but within deeper basinward structural areas where a more complete stratigraphic sequence is preserved, the Rosamond strata tend to level off into more moderate dips in accord with the

overlying lake beds of the Ricardo; this tends to obscure unconformity between the two, if such exists.

The simplest or least complicated exposure of the Rosamond section in the Kramer area is probably that which may be seen along the old Kramer-Johannesburg road that leads almost due north from Kramer railroad station. Exposures here are very inconspicuous, being chiefly in the road bed and low hills adjacent, in an area that is mostly covered by terrace gravels and alluvium. However, an apparently normal sequence of basal Tertiary beds, resting by depositional contact on the basement, can be seen. Unfortunately, neither the top nor the contact of the Rosamond with overlying Ricardo can be seen at this place, and the section is thus incomplete. The locality lies a short distance east of the eastern margin of the Geological Survey special Kramer borate district map.

At a point on the old road about 4¼ miles north from the Kramer railroad station, the base of the Tertiary section is a bed of sandstone and conglomerate which lies against the tilted surface on the basement granite on the north. This is overlain by soft shaly beds not well exposed, but within this shaly section is an iron-stained bed of cherty limestone containing veinlets of calcite opened in a prospect pit by the side of the road. This is the lower of two siliceous bands or beds that characteristically occur in the lower part of the Rosamond section. This lower band, which is more cherty than the upper, is about 250 feet stratigraphically above the base of the sedimentary section; the upper, somewhat more definitely a limestone, comes in about 200 feet higher in the section. These limestone and chert bands outcrop to the east and west, crossing the road nearly at right angles with recorded dips of 30° to 70° S., considerably contorted in detail. There are about 1,300 feet of Rosamond-type sediments, no lavas having been observed at this place.

A cross-section through the summit of Saddleback Mountain from northeast to southwest shows a similar but thinner section of Rosamond beds, truncated by erosion and capped by the Saddleback basalt of the overlying borate-bearing section.

The silicic lava of the Rosamond formation was found in a minor outcrop on the northeast point of the basalt-capped hill in the NW¼ sec. 16, T. 11 N., R. 7 W., S.B., less than half a mile southwest from the summits of Saddleback Mountain. A thin-section from a very dense red rock collected from a point just below the summit basalt at this place was apparently a decomposed rhyolite or tuff, quite siliceous, probably representing the top of the Rosamond section here, just below the basalt contact. A little fault at this place, trending N. 70° W. with 20-foot vertical throw, cuts the point of the ridge, setting the section down on the north side.

H. R. Gale reports other occurrences of Rosamond-type lavas in the region north of the Baker mine. A tuffaceous breccia containing fragments of a pinkish siliceous lava was found in outcrop on a little mound near the northwest corner of sec. 31, T. 12 N., R. 7 W., S.B., north of the prominent pegmatite peak. A thin flow of rhyolite, was found in the northeastern part of sec. 28, T. 32 S., R. 40 E., M.D., extending into the southern part of section 21, where it is associated with green and whitish silicified tuffs, characteristic of the basal part of the Rosamond section. A conglomerate containing huge boulders of rhyolite occurs in the SE¼ sec. 21, and the NW¼ sec. 27 in the same area, and is also assumed to be a feature of the Rosamond division.

A thinner section of Rosamond sediments including the cherty limestone beds and white tuffs is exposed in the Water Tank Hills just southwest from the Western Borax mine. Two bands of very cherty limestone, less than 100 feet apart, in steep and somewhat contorted structure, have held up the crest of the little northeasterly trending ridge. This ridge turns eastward at its northern end as though it might be snubbed under along a fault lying between these Rosamond outcrops and the Western Borax mine. A more isolated outcrop of limestone near the south end of this ridge seems to represent a lower, apparently blunter lenticular bed. Minor examples of the northwest-southeast type of post-borate faulting also cut this ridge.

The lower part of the Rosamond section generally contains a considerable thickness (several hundred feet) of white tuff or ash, mostly pumiceous, with sandy or finer texture. Some of this tuff is massive, but a larger amount is thin-bedded to laminated and evidently water-laid. Just south of the Water Tank Hills (in the northeast corner of section 26) some of this much-altered tuff has been mined as clay. A random sample of some of the softer more clayey material collected from this pit was analyzed by the John Herman laboratory of Los Angeles with the following results reported:

	Percent
Silica (SiO_2)	60.4
Alumina (Al_2O_3)	13.1
Lime (CaO)	5.6
Magnesia (MgO)	4.0
Iron oxide (Fe_2O_3)	0.95
Soda (Na_2O)	0.4
Strontia (SrO)	0.4
Potash (K_2O)	0.1
Manganese oxide (MnO)	0.1
Titanium oxide (TiO_2)	0.03
Total by addition	100.08

A considerable portion of this sample, perhaps one-fourth, consisted of sand, either quartz or undecomposed glass, but the rest was a uniform clay that swelled greatly and became of smooth soapy consistency upon wetting; it therefore has been tentatively called bentonite. Some layers of granitic boulders and arkosic material are interbedded with this tuff, exhibited in the southeast corner of the clay pit as it stood at the time this sample was taken. Basement granitic rock crops out along the road at the northeast corner of section 26 nearby, where a drill hole put down to a reported depth of 1,007 feet must have penetrated basement rocks all the way.

Because of proximity to the Western Borax mine, outcrops of this tuff and cherty limestone of the Rosamond have led to some fruitless prospecting for borates in other places in similar beds. Possibly some of the silicification and other alteration of these beds is of hydrothermal origin, but no economically significant amount of borates is known in beds of Rosamond age. In places the limestones look like veins and contain jasper, cherty material, chalcedony and drusy quartz, some of which cuts across the bedding. In the south central part of sec. 5, T. 11 N., R. 7 W., S.B., there is a much-silicified bed, full of jasper; the red, clinker-like Saddleback lavas to the west are also much silicified.

Beginning in the area near the center of sec. 16, T. 11 N., R. 7 W., S.B., at the southwestern foot of Saddleback Mountain, grayish arkosic tuffs of the Rosamond may be found in patch or window-like outcrops which extend to the more nearly continuous exposures that are found in the northeastern part of section 8, and thence into sections 5, 6 and 7. The jaspery limestone appears again about the middle of the S½ sec. 5, T. 11 N., R. 7 W., S.B., and may be followed westward well into section 6, where it passes under the boulder terrace cover. Here it maintains its position several hundred feet stratigraphically above the contact with the granite at the base of the sedimentary section.

These outcrops, exposing the contact of Tertiary sediments with basement granite, partially delineate the present border of the basin that contains the Tertiary. From the basal Rosamond exposures just mentioned this border may be considered as swinging far to the north of the Kramer borate district map, but masses of the basement granite appear at several places included along the north edge of the Kramer map, which can be taken as a northern border of the Kramer borate basin in a restricted sense. The prominent pegmatite peak in the southwestern corner of sec. 31, T. 12 N., R. 7 W., S.B., rises sharply out of the surrounding plains and is clearly a remnant that has held its place against erosion because of the many resistant pegmatite dikes and quartz veins which it contains. This suggests that this eminence may have existed during the time of deposition of Rosamond as well as all later beds. A similar situation probably exists at the granite and pegmatite ridge that extends from section 5 through sec. 6, T. 11 N., R. 8 W., S.B., in the northwestern corner of the Kramer special map. Limestone and jasper appear along the south foot of this ridge in sections 5 and 6, suggesting a Tertiary shore-line low on the front of this slope, against which alluvium and lacustrine beds were laid down. These contacts may also represent faulting, as the exposures are very incomplete.

A considerable section of Rosamond sediments, including a considerable thickness of beds above the limestone and jasper zone, is exposed in the east-west valley that lies along the border between sections 5 and 8 in the area referred to above, which is in the northwestern corner of the Kramer borate district special map published by the Geological Survey. A series of prospect pits dug through the valley alluvium here show gray, micaceous shale and coarse yellow-weathering quartzose sandstone, typical of Rosamond lithology. These beds are much disturbed structurally, as though by local crumpling, which may be connected with faulting. These exposures continue up to a distinct contact at the top of the section, which is overlain by basic lavas classed with the Saddleback series of flows, including the Stone House Hills to the south of the valley of Rosamond exposures.

From the last-mentioned locality, this lower division of the Tertiary sediments extends west and northwest in a broad sweep including the Muroc clay mine, continuing to the prominent peak of Castle Butte beyond. However, from the clay mine northward, the Rosamond seems to be represented in an abbreviated section which contains only the basal portion, particularly some of the cherty beds and underlying tuffs. The clay mine itself is in a small synclinal fold of the Rosamond series including the clay and cherty beds, immediately above which the little hill is capped by a nearly horizontal cover of basalt or latite, apparently a basal member of the overlying Ricardo, indicating unconformity between the

two divisions of the Tertiary. About a mile farther west and a little north, the same sequence is seen in a group of low hills, including one near the center of sec. 33, T. 12 N., R. 9 W., S.B. This seems to indicate that the Rosamond formation is only partially represented in the broad basin-like area that lies east and southeast from Castle Butte, and that the basic lavas do not extend far from the Kramer basin in that direction.

Due west from the Kramer basin, beyond the hills of basic lavas that lie between North Muroc and the clay mine, Tertiary deposits lap against a broad low dome of quartz monzonite, an eroded surface of granitic rock rising as a low barrier between the lower plains of the Kramer basin and the area around the towns of Mojave and Rosamond. This granite is intruded at places by volcanic rocks of Rosamond age, and at one place in T. 11 N., R. 10 W., S.B., there is an isolated patch of basic lava, which looks like a cap resting on the granite.

Except for the group of old rocks exposed in the Amargo Hills south of the borax mines, little to nothing is known of closure, if any, to the Tertiary basin that contains the borates in a direction toward the southwest from the borate-bearing area. The present land surface is a gravel-covered plain, suggesting an upper terrace which descends to a level some 50 feet in elevation above the surface of Muroc Dry Lake, but is an evenly graded alluvial slope so far as the Kramer borate district is concerned. A few drill holes sunk in this direction indicate that sediments like the Rosamond division extend deep in this area of plains surface southwest of the borate area. However, by almost any method of reasoning as to conditions that existed during the accumulation of the borates, it seems that drainage must have existed leading from the borate area in the general direction of Muroc Lake or basin, and some overflow of soluble borate material probably passed on down in that direction.

The area that lies in general directly north of the borate basin proper was examined more particularly by H. R. Gale in January 1939. Here, in the vicinity of the water wells that supply the Baker mine and concentrating plant (southwest corner of sec. 2, T. 11 N., R. 8 W., S.B.) the Saddleback lavas apparently dip into a shallow syncline, which extends far to the north of the area covered by the Kramer special topographic map. In the northern part of this area Rosamond beds whiten the face of gently dipping ridges, especially near former volcanic vents. This syncline is bounded on the north by a sharp cherty limestone anticline, forming an east-trending ridge, flanked by coarse, gritty sandstones (approximately sec. 11, T. 32 S., R 40 E., M.D.). North of this ridge is an extensive synclinal or downfaulted area which reaches from the hills of the Kramer district to the mountains around Randsburg and Atolia. Limestone of Rosamond type, with some gypsum, is exposed in scattered outcrops at various places on this plain, noted particularly near the middle of the east side of T. 31 S., R. 40 E., M.D. Description of the section underlying this plain is reviewed in the account of the Stuart Chevalier well in the SW$\frac{1}{4}$ sec. 35, T. 31 S., R. 40 E., M.D., in this report.

A broad area of plains lying to the northwest of the Kramer basin was examined in some detail by the writer, and is significant with respect to the relation of the Rosamond volcanics and associated sediments to the Kramer area. Castle Butte, Desert Butte and some nearby smaller peaks or ridges are conspicuous volcanic necks of rhyolitic and somewhat more basic rock which mark a line of main vents and a well-defined axis of uplift, that brings up the granite (quartz monzonite) to form a most

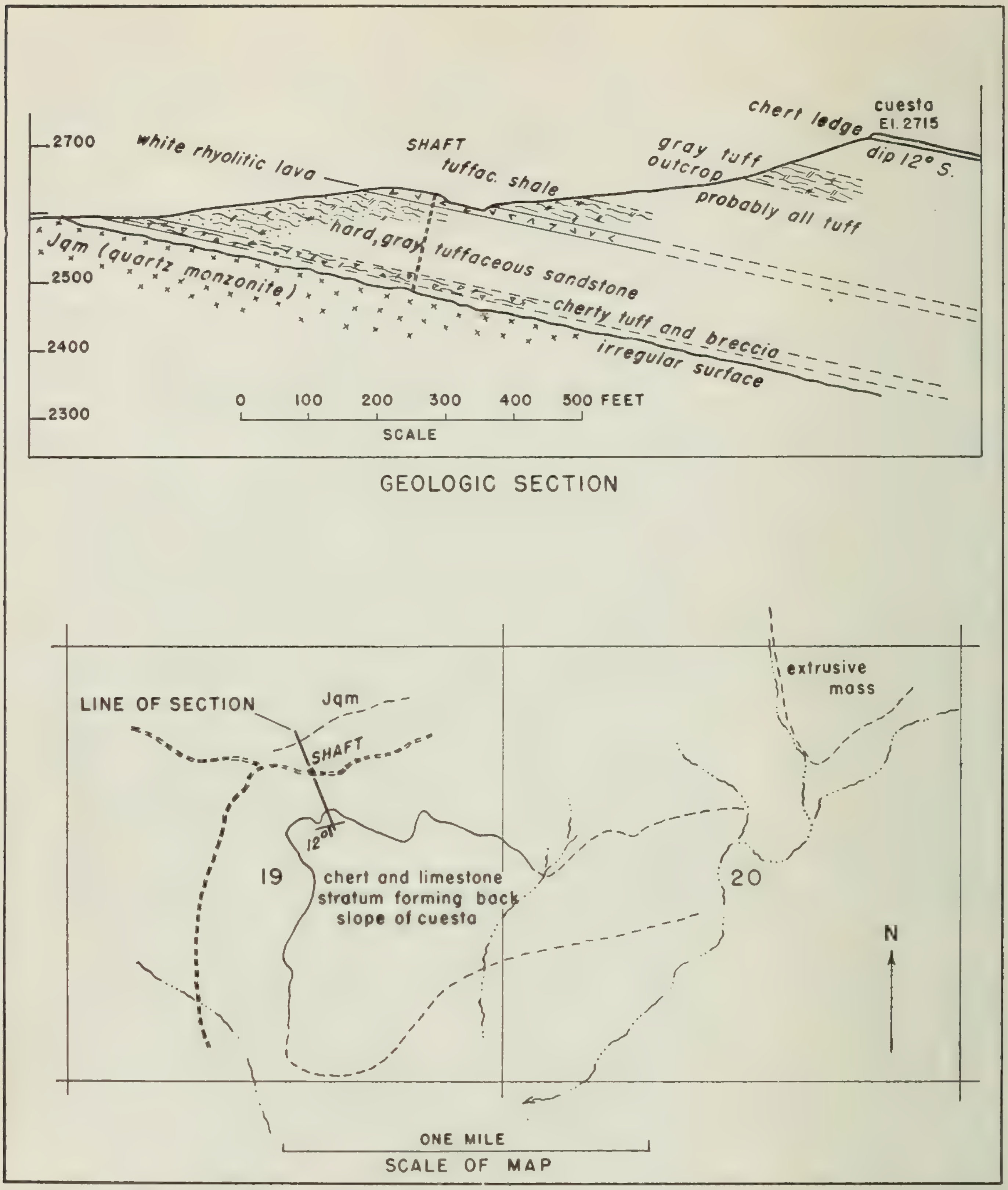


FIGURE 2. Map and profile with cross-section showing details of lower part of Rosamond formation 3 miles northeast of Castle Butte, secs. 19, 20, T. 32 S., R. 39 E., M.D.

northerly limit of the Kramer basin extended to include all of the relatively lower structures on the south of that border. Pyroclastics and sediments of Rosamond type flank this line of mid-Tertiary uplift on both sides—to the northwest and to the southeast. Attached to the central plug of volcanic rock at the immediate base of the summit rocks of Castle Butte, quartz monzonite appears at high elevation as though it had been dragged up with the lava, and around this center is spread a sheet of pyroclastic accumulations of gray tuff and breccia, often capped by a sheet of siliceous sinter. At greater distance from the vents, even within a mile or two, these tuffs take on a distinctly water-laid aspect, and the order of the units composing the section becomes more regular. For some distances stratification of the section remains horizontal or only slightly inclined. The material is in most places firmly consolidated, mainly whitish tuff, with more or less admixture or interbedding of micaceous shale and arkosic sands essentially similar to the tuff that makes up the greater part of the Rosamond formation at the type locality. Cherty limestone, like that found elsewhere in the lower part of the Rosamond section is at places conspicuously exposed, forming the capping of ridges or cuestas in the present topography. This area, somewhat remote from the Kramer basin proper, is of special interest because of the display there of features that are characteristic of the Rosamond division of the Tertiary elsewhere.

A clearly revealed cross-section of the basal part of the Rosamond sequence of deposits is exposed on the north face of a small cuesta ridge in sec. 19, T. 32 S., R. 39 E., M.D., 3 miles northeast of Castle Butte. A map of this locality and cross-section are shown in figure 2. The quartz monzonite basement is exposed north of this locality, the contact with the Tertiary being clearly traceable. A bright green cherty tuff and breccia bed immediately overlies the granitic basement, a distinct band of bright color along its outcrop. Similar green siliceous tuffs have been noted at corresponding positions in the vicinity of the Kramer basin. Above it are tuffs and arkosic sandstones including a thin sheet of white rhyolitic lava about 150 feet stratigraphically above the base of the section. About 375 feet up in the section a massive stratum of black-weathered chert, mingled with creamy yellow fresh-water limestone, forms the top and south-sloping face of the ridge. Farther to the northeast are similar exposures representing approximately the same section. Softer beds come in higher in the section and are generally eroded and covered by later deposits. Constancy exhibited in these basal members of the Rosamond section over a wide extent of this part of Mojave Desert indicates low-lying to nearly flat topography over much of this area at the time these beds were deposited.

Pre-Tertiary Rocks

Older Formations

The basement that prevails in this region consists largely of massive crystalline rock of the same general class as granite, but more specifically defined for this area as quartz monzonite with some variations. It is composed essentially of obvious quartz, feldspar, and the shiny black flaky crystals of biotite mica. Generally, it is coarsely crystalline and light gray in color. It is similar to, and probably part of, the great batholithic intrusions that form the cores of the Sierra Nevada.

This granitic rock was intruded into older rocks of diverse sorts, here included under the general designation of basement complex. Near

the Western Borax mine are micaceous schists which are of the character of metamorphosed sediments classed with the pre-Cambrian elsewhere, but for which no such determination of age seems possible here. Paleozoic sediments, present in this general part of the Mojave Desert region, are not specifically recognized in the vicinity of the Kramer district. A group of altered volcanic rocks and minor intrusive bodies is found in the low hills beginning less than a mile southeast of the Baker and Western mines, lying on both sides of the paved road that connects the mines with the setttlement near the railroad formerly called Amargo, but now called Boron. To this group of rocks the name Amargo was given during the present field work in 1935. They are evidently unmelted remnants of rocks that were intruded by the quartz monzonite, apparently portions that floated on the upper surface of the granitoid batholithic magma during its intrusion. They are older than the monzonite, which is believed to be of late Jurassic age, but because of similarity to rocks elsewhere that have been classed with pre-batholithic intrusion Jurassic, they are here tentatively assigned to Jurassic.

Areal mapping of the various types of rock of this group found in the Amargo Hills has been carried out by H. R. Gale, who has studied the area in some detail, but as the whole association is a part of the older basement complex that underlies the borate-bearing Tertiary, it is not of importance to discuss this geology at the present time. A general recognition of the basement rocks is important to the extent that they be differentiated from the overlying Tertiary. In place, or in less disturbed positions the basement rocks are usually distinctly harder than the much younger Tertiary formations, and so are readily distinguishable. However, in the Kramer area, particularly in the Amargo Hills, these rocks include some older lavas and pyroclastics that resemble some of the acid lavas of the Tertiary. Also, most of the Tertiary sedimentary sequence consists of detritus derived from the basement rocks and distributed by waters that flowed over the land surface in Tertiary time.

All of this part of the Mojave Desert was deeply eroded after the intrusion of the quartz monzonite. This is necessarily so because plutonic igneous rocks to which class the quartz monzonite belongs, crystallize with a texture which shows that they solidified under cover of thousands of feet of overlying deposits. As these plutonic rocks are now extensively exposed on the present land surface, showing traces of an old erosion surface where the contact with the overlying Tertiary can be seen, the land must have been deeply worn down, and most of the former cover over the quartz monzonite destroyed before Tertiary deposits began to accumulate.

In general the evidence indicates that this part of the North American continent remained above sea level, or at least was not connected by drainage with the sea, throughout the long Cretaceous period, and also through the early part of the succeeding Tertiary, and that during that time this land was drained by streams that flowed outward toward the then-existing oceans. These outward-flowing waters removed all or practically all of the products of the disintegration of rock surfaces as they were then exposed. At the close of this very long period a relatively thin residue of sand, water-worn gravel, and boulders, the latter especially in the more lately occupied channels of streams, was spread over the old land surfaces, and the rocks exposed were, in general, deeply decomposed by weathering. Remnants of these meager deposits at the

base of the Tertiary section are all that remain to represent the long stage of early Tertiary deposition in this part of the continent.

MINES AND PROSPECTS

Evidence Developed in the Mines

The most remarkable feature of the deposits in the Kramer area is the occurrence of massive crystalline bodies of sodium borate that is almost pure, in the sense of being free of admixture of other salts commonly found in desert saline accumulations. Reference has already been made to the form, extent, and thickness of these deposits, which contain such an amount of natural borax that there certainly will be no lack of the material in this country for a great many years to come. These sodium borate deposits were first opened and developed at the mine of the Pacific Coast Borax Company in the northeast corner of sec. 24, T. 11 N., R. 8 W., S.B. Subsequently these operations were transferred to a shaft in the northwest corner of sec. 19, T. 11 N., R. 7 W., S.B., and the whole is now called the Baker mine. Two other mines, opened independently shortly after the Baker mine was put into production, have yielded large tonnages of sodium borate. These are the Suckow Borax Mines, Consolidated, Incorporated, which put down a shaft 1½ miles west of the No. 1 shaft of the Baker mine, and the Western Borax Company, Limited, whose mine lies about half way between the other two and approximately half a mile farther south. These mines were at first assumed to be on three separate deposits, but it seems more likely that these were originally parts of one continuous deposit, now somewhat displaced by faulting. All three of the mines, and practically all of the property that can be considered as proved borate-bearing ground in the Kramer district, subsequently passed into the ownership or control of the Pacific Coast Borax Company, or actually under the Borax Consolidated, Ltd., of London.

The accompanying map and cross-sections developed therefrom (plate 52) are compilations by the writer, based on surface geology and underground evidence as developed in his various engagements and studies conducted in this area. This map shows the location of most of the bore holes put down within the map area in exploration for the borates up to the time of its construction. It should be explained that the outline shown on the accompanying map of the main borate body is largely tentative, for lack of more definite information, but is probably approximately correct. The contours represent structure of the borate-bearing beds as indicated by the base on which they rest, this being the top of the first lava encountered in drilling or other development.

It happens that each of the three principal mines is situated at the outer border of the main deposit, in fact these mines now seem to mark the three corners of a roughly triangular area that includes the main body of the known crystalline sodium borate deposit. As will be explained in later discussion of the origin of these deposits, it appears that this area must represent the locus of the water body, from which the sodium borate first crystallized as tincal or native borax, precipitated out of solution in the water on the bottom of a shallow lake, in bedded accumulation laid down by such precipitation. The present range in elevation of the sodium borate beds and underlying basaltic lava sheets, from about 2,100 feet above sea level to a depth of about 1,500 to 1,700 feet near the Western Borax mine, is due to deformation of these deposits since they were laid down and covered by other deposits.

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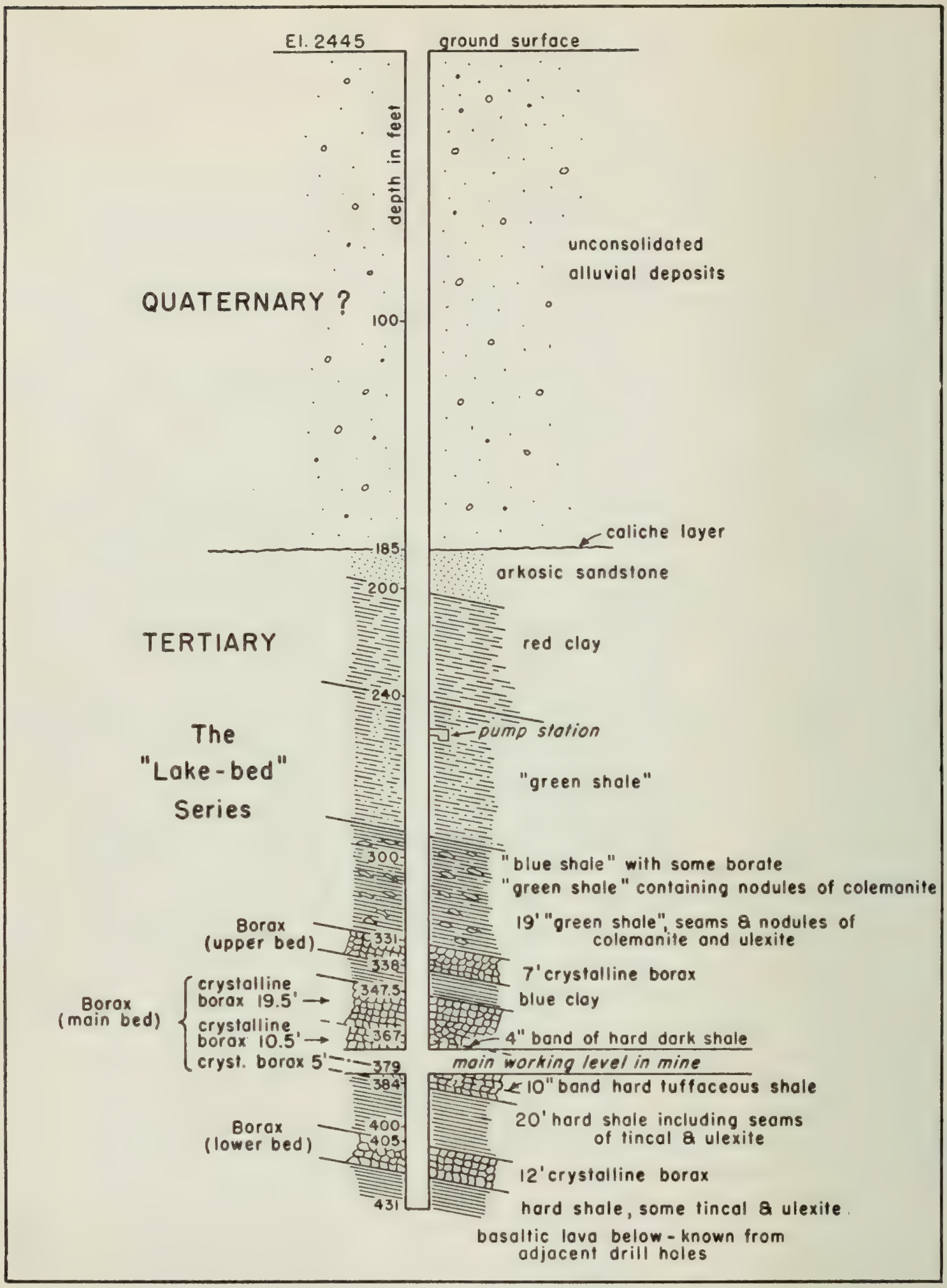

FIGURE 3. Vertical section through original shaft on the Suckow Borax property, sec. 14, T. 11 N., R. 8 W., S.B.

Suckow Mine

The sodium borate deposits in the Suckow mine in the southeastern corner of section 14 are more nearly in the original form in which they were laid down than are the deposits in either of the other two mines. In this northwestern part of the main deposit native crystalline borax or tincal is regularly interstratified with its associated Tertiary lake-bed sediments.

Native borax constitutes by far the most of this deposit, chiefly in the original or primary bedded form, but includes innumerable secondary veins of borax commonly crosscutting the bedding. Ulexite, apparently in the form of secondary veinlets or nodules in the clay that is associated with the borax, is common. Probertite has been identified (Murdoch, J., 45) with ulexite from the Suckow mine in instances in which the ulexite is clearly a product of alteration from probertite.

Although this part of the deposit has been somewhat deformed by tilting and minor faulting, the borax or tincal remains in very much the same form in which it originally crystallized, in bedded layers, more or less mixed or interfingering with the sediments. The deposit is obviously syngenetic—that is, laid down by crystallization out of water solution, the borax having been deposited along with accompanying sediments, and in general simultaneously with them.

The original shaft of the Suckow mine, the location of which is approximately 750 feet east and 85 feet north from the quarter-corner on the south side of sec. 14, T. 11 N., R. 8 W., S.B., was sunk to a depth of 431 feet, and passed through 3 main beds of crystalline tincal, these being separated by beds of shale. Bore holes nearby indicate that the shaft was bottomed at that time in the basal lake-bed shale that overlies the top of the first lava bed. The section penetrated by this shaft is represented in the accompanying diagram (Fig. 3). Although this shaft section was examined and measured by the writer, this was done after the mine had been in operation for several years, and by removal of some of the lagging with which the shaft had been timbered, so that it seems best to use the original depth measurements recorded in the engineering records of the company, which have been extensively quoted in documentary evidence. Three beds of tincal, aggregating some 50 feet thickness in all, are distributed through a section of strata about 80 feet thick. The lateral limits of the Suckow deposit had not been reached at the time of the writer's examination (January 1932), when underground developments were as indicated on the map. The structure symbols shown on this map indicate a gentle northeasterly dip throughout the area then exposed, the dip steepening in proximity to a little northwest-trending fault which was the northeast limit of most of the workings opened to that time in the northern part of the mine. The faulting and tilting of the originally horizontal beds probably belongs to late deformation in the region.

A second shaft was put down by the Pacific Coast Borax Company about 225 feet due north of the original Suckow shaft, and developments have now been much extended beyond that shown on the accompanying map.

The internal structure of these masses of bedded tincal is shown by the accompanying photograph, (pl. 54) which was taken by the writer in the Suckow mine. This shows the stratification of the deposit, with some distinct interbands of sediment (dark-colored layers). The tincal is

whitened on the surface by alteration from contact with the air to tincalconite, an alteration involving a loss of part of the water of crystallization from the borax. In some layers the tincal shows the forms of original crystals of borax, with somewhat diverse orientation, more or less encased in mud or clay. The white seams transverse to the bedding are secondary veinlets of borax or tincal filling fractures in the sediments that are evidently the result of shrinkage since they were consolidated in the deposit. This view is from a portion of a few feet of the main bed of tincal, which was exposed to a height of about 10 feet in the mining development. This lies above what was called at the time the 10-inch parting, which is cut in the original shaft sunk by the Suckow company a foot or more below the floor at the shaft on the main mine level. This 10-inch parting carries well-defined ripple marks on its upper surface. These are very regular and well preserved, and are of the parallel-rib type that is produced by wave motion in a body of standing water. The ribs have a longitudinal orientation of N. 10° E., suggesting wind that blew at right-angles to that direction, perhaps like the winds that prevail in the vicinity of the mines at the present time. A small egg with an oval shell like an ordinary hen's egg, or perhaps like the egg of the desert turtle, was found embedded in the tincal in place in the Suckow mine, by the operators there at about the time of the writer's visits. This specimen is understood to have been deposited with the Geological Department at the University of California at Los Angeles.

The borax beds in the Suckow mine occur in extensive layers in such regularly stratified form, interbedded with clay or shale of evenly bedded to thinly laminated structure, that there can be no reasonable doubt that they were laid down in standing water. The distinct banding of the deposits at places suggests periodic precipitation of the borax alone, which might have been the result of chilling of a saturated solution. The shore lines of the pool or lagoon in which this deposition took place are revealed in part by developments on the sodium borate beds underground. This was noted by the writer in the mine to the north and west from the main shaft, and general reports concerning further extension of these developments since the time of the writer's examinations state that almost the whole thickness of the main bed of tincal was found to pinch off very abruptly, against a succession of somewhat varying shore lines. Beyond these borders of the sodium borate beds, borings have revealed the existence of colemanite and ulexite in scattered nodular deposits occupying the clay that is approximately correlative with the section that contains the sodium borate crystal body in the mine.

A recent paper by Dr. Joseph Murdoch (45) records the careful identification of probertite with ulexite, occurring as lenticular nodules in the shale that is associated with the native borax of the Suckow mine. Probertite was reported (November 1931) in a specimen collected by the writer from one of the interbands of shale within the main body of borax in the Suckow mine, which report was later denied; but the occurrence of probertite in this deposit is now confirmed. One peculiar occurrence resembling "cone-in-cone" structure consists of a compact fibrous form of ulexite similar to material described by Schaller (30).

A remarkable feature of this deposit is that the soluble part consists so almost exclusively of borax, without admixture of other salines. A careful sampling of the entire thickness of 31 feet exposed in the mine at the time of the writer's examination yielded the following results:

Section of main borate bed of the Suckow mine

No.		Thick-ness	Analysis (samples as received preserved in glass jars)		
			H_2O	B_2O_3	Insoluble in water
1	Borax (tincal) bedded, crystalline	3′ 10″	33.27	34.10	9.17
2	Clay or shale interband, red and green mottled	2″			
3	Borax, as above	5′ 10″			
4	Hard shale, reddish, called the "whiskey streak"	2″			
5	Borax, as above	4′ 2″	29.22	30.01	15.32
6	Hard shale	7″			
7	Coffee-brown shale	1″			
8	Borax, as above	2′ 4″			
9	Shale, hard	4″	32.20	29.73	13.76
10	Borax, uniform, crystalline	5′ 4″			
11	Hard, arkosic bed, ripple-marked	10″	(Not	tested)	
12	Borax, crystalline, includes several ½ to 1-inch beds of dark to black shale, interlaminated with very even bedding	5′ 5″	28.76	28.66	17.10
	Total thickness	31′			
	Only a trace of chlorides was found in any of these samples.				

At the time of the writer's examination in September 1931, total output from the Suckow mine, 1927-31, inclusive, was reported by the company to have been 11,690 long tons of borate materials or concentrates sold, derived from an estimated 20,790 tons of crude ore actually removed at the mine, calculated from a measurement of the cubic contents mined up to that date, and a factor of 113 pounds per cubic foot of product removed. Later (about January 1, 1943) another estimate was made which is understood to have yielded a total of 187,000 short tons of crude borate and waste removed to that date, out of a calculated total of 900,000 tons originally contained within the Suckow property.

Western Borax Mine

Property and Location. The property of the Western Borax mine lies on the south edge of the Kramer borate basin, including only some 5 acres surface area of the main borate body of the Kramer field. This is a narrow band a few hundred feet in width extending along the north boundary of the S½ sec. 24 for about a quarter of a mile each way from the center of the section. The property as a whole embraced the S½ sec. 24, and the N½ N½ sec. 25, T. 11 N., R. 8 W., S.B. The S½ sec. 24, which includes the mine and all of the borate deposit on the property, so far as known, was covered by two 60-acre association placer claims, located July 23, 1926, by W. F. Balling et al., under the names "Tincal No. 1" and "Tincal No. 2." Title to this property was subsequently trans-

ferred (1) to W. H. Brewer, April 15, 1927; (2) Brewer to A. M. Buley, June 23, 1927; (3) Buley to Western Borax Company, Ltd., May 27, 1930; and (4) sold by Western Borax Company to United States Borax Company (subsidiary of Borax Consolidated, Ltd.) May 12, 1933.

Technical discovery of borate showings were recorded with the filing of the association placer claims referred to above. Later kernite was disclosed in a bore hole—the first drilled by Western Borax—on July 4, 1927. W. M. Balling was primarily responsible for the discovery and development of this part of the Kramer borate deposit.

Surface Geology. No outcrops of the borate-bearing section exist in the vicinity of the Western Borax mine. A short distance south of the mine older rocks of Rosamond type are exposed in the little ridge to the southwest of the mine, called the Water Tank Hills, and to a lesser extent on the north face of the Amargo Hills to the southeast. There is such a discrepancy between the elevation of these older Tertiary rocks and the depth of the borate section in the Western Borax mine that some structural displacement is indicated between them. Two bands of very cherty limestone crop out along the crest of the Water Tank Hills in steep and somewhat contorted structure. Traces suggesting algae have been found by the writer in portions of this limestone. Gray tuffaceous beds make up most of the section represented in Water Tank Hills and basement granite (quartz monzonite) is exposed on the pediment at the southwestern base of these hills, notably along the dirt road in the extreme southwestern corner of section 24. Thus the Water Tank Hills represent the very base of the Rosamond section. A prominent big boulder conglomerate outcrops along the northwest face of the Water Tank Hills. This is assumed to be the same as the big boulder conglomerate which was passed through above the lake beds in sinking Western Borax shaft No. 1. It is considered to be a post-borate member of the Ricardo formation. The materials in this conglomerate are evidently derived from the granitoid rocks now exposed immediately to the south of the conglomerate and Rosamond outcrops, and so the lack of lava boulders in its composition can be accounted for. If this identification of the age of this fanglomerate member is correct, there must be a considerable unconformity between the conglomerate and the Rosamond beds of the Water Tank Hills section.

Although it is possible that a part of the displacement between the mine and the Water Tank Hills could have taken place along a fault trending in a northwesterly direction, there is evidence that the bulk of this displacement occurred along a nearly due east-trending fault. This fault must pass very close to the mine, south of drill hole No. 8 and the deep shaft No. 3, probably south of drill hole No. 3, but close to the shallow shaft No. 2, and almost exactly through drill hole No. 4. Its trace probably does not come to the surface but is buried beneath the big granite boulder conglomerate which has here been called the Western Borax conglomerate, thought to be of Ricardo age. Hence shaft No. 2 is not affected by this fault. Because of its proximity to the mine and its important bearing on the mine, this buried fault has been called the Western Borax fault.

Bore Holes and Shafts. The first drilling on this property near the subsequent location of the mine was a hole credited to Pacific Coast Borax Company (their No. 35) about 1,350 feet east and 250 feet south

from the center of section 24, reported by C. M. Rasor (testimony in court) as ''500 or 600 feet deep, in which we struck no borates.'' W. M. Balling then put down a core hole only a few feet distant from No. 35, calling it his No. 1 hole, which went to a depth of 875 feet through conglomerate and shaly beds; a green flame test for boron was reported from light-brown to blue sticky shale at about 650 feet depth, and again in greenish silt material from just below 800 feet. However, important results were obtained in the first 2 holes drilled by Mr. Balling under Western Borax management; the No. 1 located about 200 feet southeast from the stake marking the center of section 24; and No. 2 about the same distance southwest of that point. Crystalline sodium borate was encountered first in the No. 1 hole at the depth of 850 feet, continuing to 962 feet, and in No. 2 hole a corresponding section of borates was encountered between the depths of 770 to 868 feet. Both of these drill-hole records were checked almost exactly in subsequent mining development. Several other holes were drilled in this vicinity, adding further data on distribution of the borates while development of the mine was going on.

The original shaft (No. 1) through which practically all of the material produced from the Western Borax mine has been taken out, is situated 290 feet south and 350 feet west from the center of section 24. This shaft was put down through 640 feet of granitic sediments, including sand, gravel, and boulders, some of the boulders being of very large size. This is the section locally reported as ''over-burden.'' There has been some uncertainty as to how much of this, if any, should be included as Quaternary alluvium, and how much classed with the post-borate Tertiary conglomerate. The writer is inclined to class almost all of it with the Tertiary, as consolidated conglomerate of Tertiary type is found in shallow shafts nearby. From 640 feet down, the section penetrated by the shaft was described by the operators as ''lake beds, more or less conglomeratic'' to the depth of 721 feet, but no mention of distinct bedding or direction of dip and strike seems to have been preserved. The next division recorded is of sandy shale to 780 feet, then sediments of more typical playa type described as blue shale, which carried ulexite and colemanite in the shaft section. However, the main shaft of the Western Borax mine missed the sodium borate and revealed neither kernite nor tincal. The shaft station was established on the 856-foot level and a crosscut run N. 36° E. in the general direction of the top of the sodium borate found in the No. 2 hole. The shaft station and first 100 feet of the crosscut passed through a section of footwall shale which strikes northwest and dips northeast, mostly at low angles, averaging about 10 to 15 degrees. Thirty-five feet of the footwall shale is thus exposed. It contains many thin veins of drusy, pearly opalescent ulexite and white, almost granular, material that was found to be mainly probertite. Some of the veinlets parallel and some cut across the bedding of the shale. They are therefore clearly secondary to the body of the shale country rock. Small rounded clusters of radiating, glassy, needle-like crystals of the mineral probertite are scattered through the shale; in fact it was here that the mineral collected by Dean Frank H. Probert was determined by Dr. Arthur S. Eakle and named probertite. On the walls of the shaft station the shale is finely micaceous, gray to greenish in color, clay-like and fairly regularly bedded. So far as known there is no colemanite in the footwall shale. A few bands containing nodular layers of howlite—very

hard, dense, white, and porcelain-like—were found in the footwall shale on the 950-foot level of the Western Borax mine.

Shaft No. 2, which is 250 feet south of shaft No. 3, was apparently started when the ore body was expected to extend farther to the south than it was later found to do. This shaft was carried to a depth of only 197 feet, where the shallow groundwater was reached and operations discontinued. Except, possibly, for some alluvium at the surface and 20 feet of volcanic ash encountered between the depths of 100 and 120 feet, it was all in granitoid-boulder Ricardo conglomerate. Since this conglomerate is believed to cover the Western Borax fault, as a bajada deposit does, this shaft is of no help toward locating the fault more precisely. However, to the west, drill hole No. 4, which was situated 950 feet south and 1700 feet west of the center of section 24, on the very edge of the outcrops of the limestones and tuffs of the Rosamond at the north end of the Water Tank Hills, instead of going into the Rosamond, passed through only granitoid sediments to a depth of 1126 feet. The sediments were reported as more of the ''lake series'' (upper fanglomerate) type below 604 feet. It seems probable, therefore, that this hole started close to where the fault had been at the surface, in the Western Borax conglomerate that filled in over the eroded escarpment, and that its lower part, at least, is on the north side of the fault.

No. 3 shaft, the location of which is 420 feet south and 220 feet east from the center of sec. 24, T. 11 N., R. 8 W., S.B., is now in use chiefly as a safety exit and for drainage of water that enters at several points within the mine. The long (No. 3) east winze descends from the main level in the mine approximately 100 feet lower where a long crosscut leads off to the south and joins the No. 3 shaft on the 950-foot level. The log of the No. 3 shaft is recorded only in very general terms as follows:

Depth (feet)	Thickness (feet)	Description of formation penetrated
0–770	770	Granitic sediments
770–820	50	"Lake-bed deposits"
820–929	109	Shale, including some borates, probably ulexite stringers
929-930	1	Colemanite, probably a nodular layer in shale
930–942	12	"Ulexite" probably disseminated in shale

Entering the shale containing borates at a depth of 820 feet, this section seems to correspond approximately with that found in the No. 1 shaft, except that it seems to lie about 40 feet deeper. This is in accord with the general structure of the deposit indicated by development in the mine. No sodium borate was found in the No. 3 shaft and so it is assumed that the zone corresponding to sodium borate in the mine is occupied by shale containing calcium borate minerals there. At the main station level, which, as stated, is at a depth of about 950 feet, a sump has been sunk some 25 or 30 feet deeper exposing clayey sandstone and conglomerate which, as discussed elsewhere, is known to underlie the footwall shale.

Mine Developments. The main crosscut leading into the mine continues on the same northeasterly course, passing first into solid crystalline tincal and a short distance farther into kernite with more or less shale. Some of the kernite in this part of the deposit is in the form of large idiomorphic crystals surrounded by shale, arranged approximately

along original bedding of the shale. Irregular masses of relatively clear crystalline tincal occur at various places within the body of the deposit. Passing northeastward in the general direction of the dip of the deposit, the main crosscut or drift thus passes into the body of the deposit with the bottom of the sodium borate descending below the floor level at angles that probably average about 10 to 15 degrees, steepening locally. Raise No. 1, 60 feet south and 190 feet west from the center of section 24, carried up about 30 feet from the floor (20 feet from the back or roof on the main level) passing through the crystalline sodium borate left to hold the ''back'' in the mine, cutting an intermediate body of shale represented at this place by a cemented stratum called the ''*hard streak.*'' Mr. Balling says that this is not the same kind of material that was described as a hard streak, 10 feet in thickness, encountered in sinking the No. 1 shaft from 27 to 37 feet above the station floor level. However, this hard streak in the No. 1 raise, where it is 18 inches thick, is continuous toward the east, forming a division in the ore body about midway between top and bottom. As this dividing shale passes eastward it increases in thickness to about 7 feet, as far as at present recorded.

Numerous lateral drifts extend east and west from the main crosscut on the 856-foot level as described above. At the point where the ore was first encountered, the approximate base of the sodium borate beds is followed toward the east by an entry called the ''footwall drift.'' Within this drift two raises have been opened, which, unfortunately are not incorporated in the diagrammatic cross-section herewith. These raises pass upward into shale almost immediately above the back or roof of the drift. This seems to indicate that the sodium borate body is thin here, represented by only some 15 to 20 feet of crystalline sodium borate of the lower part of the deposit, and there overlapped by shale. Termination of developments on upper-level workings, above the intermediate shale, indicates that the limit to which the upper half of the deposit extends lies considerably farther north than the position of the footwall drift. Conversely the deposit seems to thicken toward the north.

Most of the available ore has been removed up to within a few feet of the north boundary of the Western Borax property. Actual recovery, as indicated by a rough estimate from the mine map, seems to have been not much more than about 50 percent of the original ore present in the part of the deposit that has been worked. The remainder stands in the pillars and in the ''back'' or roof. Development in the Western Borax mine has been done by a rather unsystematic plan. The upper level is no longer accessible, at least not until some system of ventilation has been arranged. Four winzes lead to lower levels that have been rather extensively mined.

Thickness and Tonnage of Ore. The sodium borate deposit is essentially a solid body of crystalline sodium borate salts (or minerals) as represented in the Western Borax Company mine. This body ranges from approximately 60 feet in thickness throughout the western half of the mine as it now exists. East from the main crosscut the crystalline sodium borate body bulges to a thickness of 110 feet, and seemingly pinches off rapidly toward the eastern end of the mine development.

The problem as to what becomes of the main orebody at the eastern limit of the mine remains unsolved. Unfortunately, the No. 3 winze has been filled with water in its lower end, the No. 4 entry, some 75 feet east of

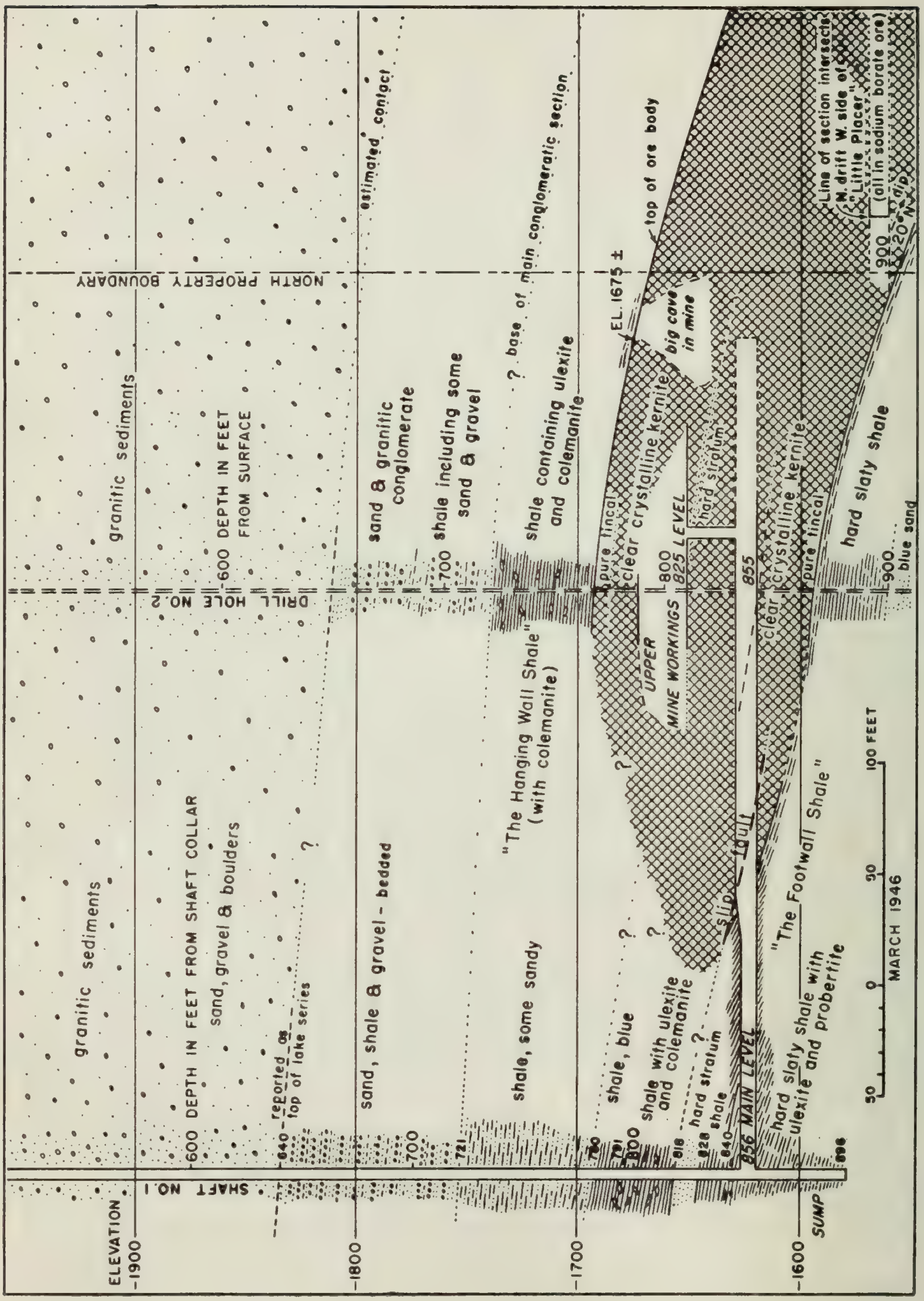

FIGURE 4. Vertical section through Western Borax mine extending from the No. 1 shaft to the northeast

the south cross-cut leading to shaft No. 3, and development in line of the long winze which at one time extended 160 feet east from the intersection of the south cross-cut is now inaccessible. This lower end of the winze seems to run out nearly on a level, passing into shale which has a northeasterly dip. This shale may be a thicker representative of the intermediate shale. If this is so, it may be that the upper part of the ore body has pinched out at this place, and that the lower division, although here possibly maintaining a representative thickness of some 40 or 50 feet, turns downward with steeper dips toward the northeast, and passes below the 950-foot level of the mine.

There is also another as yet wholly unsolved problem, which concerns the structural relations of the kernite reported in drill hole No. 8 between elevation points 1630 and 1475 feet. This is a matter that deserves further exploration, perhaps by means of a cross-cut run out from the south cross-cut on the 950-foot level, with a possible raise and shaft at the approximate position of the No. 8 drill hole.

It is reported that 160,000 short tons of crude borate ore was extracted by Western Borax Company during its operation of the mine, and very little has been taken out since. This product, representing a recovery or extraction of not more than 50 percent of the ore in sight within the area worked, is what was recovered from just about 5 acres of actual deposit. Some ore remains at places that probably could be safely recovered, and various estimates of the amount of such reserve have been casually expressed by persons in position to know more or less about the situation. It has been stated that some 6000 tons of such reserve is in sight at the present time. E. E. Knapp, who was engineer at the Western mine at the time that company ceased operation prior to sale, has made some estimates which range from 10,000 to perhaps 12,000 tons of ore in reserve and safely recoverable.

The proportion of shale to crystalline borate ore varies quite irregularly at places. On the average the ore removed during the Western Borax operations has been quoted to the writer at 10 to 15 percent shale or insoluble. However, some of the ore considered still available lies at the western end of the mine, and some of the ore body is said to become more shaly in that direction, reportedly 25 percent insoluble for a part of the bed. The Western Borax deposit is a marginal phase of the Kramer deposit as a whole, and probably has more sediment included with the sodium borate than is to be expected farther out (north) toward the center of the original deposit.

Baker Mine

The Baker mine of the Pacific Coast Borax Company is now represented by 3 shafts, the locations of which are indicated on plate 52. The No. 1 shaft in the northeast part of sec. 24, T. 11 N., R. 8 W., S.B., was used only during first development on the deposit and for preliminary operation, after which the main or No. 2 shaft was put down in the northwest part of sec. 19, T. 11 N., R. 7 W., S.B., which since August 1927, has been the main operating outlet for the mine. A No. 3 shaft, used only in an auxiliary way, is located about 400 feet north of the southwest corner of sec. 18, T. 11 N., R. 7 W., S.B., very nearly on the west boundary of that section.

In this mine the general form of the crystalline mass of sodium borate minerals seems to be that of a broad flat-topped anticlinal nose with a plunge to the southeast. The log of this shaft, taken from records

of proceedings in public hearings with some supplement from testimony by company officials in the same connection, is as follows:

Log of shaft No. 2, Baker mine

Location: 300′ E. and 450′ S. from NW. corner of sec. 19, T. 11 N., R. 7 W., S.B., elevation at collar 2498′

Depth (feet)	Thickness (feet)	Description of formation penetrated
0–375	375	Alluvial sediments, sand, gravel and boulders, including shale in lower part
375–393	18	Shale, "blue," including colemanite and ulexite
393–498	105	Crystalline sodium borate, both kernite and tincal, with some interstratified shale (first mining level 408′ depth, elevation 2089′) (second level, intermediate) (third level, 485′ elevation of floor 2013′)
498–540	42	Shale, brownish gray, contains minor seams or flakes of ulexite in upper part

Although not stated in the log, it is here assumed that the bottom of this shaft (as shown in the log above) is at the top of the underlying basaltic lava.

In comment by company officials, also made during public hearings involving this property, it has been stated that the No. 2 shaft penetrated the sodium borate body near the maximum known thickness of the body in the Baker mine. It has been assumed that the outline of the "ore body" of the Baker mine has been quite distinctly traced by mining development. This is undoubtedly true for the definite limits of the sodium borate to the north and northeast from the No. 2 shaft. As testified by C. M. Rasor, this deposit extends in mass about 150 feet north from the No. 3 shaft, on the upper or 408-foot level, whereupon the sodium borate mineral cuts off abruptly, without faulting, but by transition through a steeply inclined wall into relatively barren shale, that is, shale that presumably carried only scattered patches of calcium borate minerals. This cut-off is described as being effected by a sharp turn-down of hanging wall, "where the ore comes right up against a wall and stops." East from the No. 2 and No. 3 shafts the sodium borate cuts off in similar manner along a line that trends southeasterly from the point north of the No. 3 shaft described above. This line seems to mark part of the original northeasterly limit of the sodium borate deposit. The "footwall" of the deposit is followed by a winze that leads south from near the third level station on the No. 2 shaft, on a dip of 8 to 10 degrees for some 200 feet, when the beds dip off more steeply toward the southeast and apparently shelve off more gradually to the southwest, the latter in the direction of the Western Borax mine. Mr. Rasor has testified that he "does not believe that the Baker deposit is continuous to the Western Borax deposit, although it might be." From surface geological evidence, it seems that the deposit in the Baker mine may be cut off by a normal fault of northwest trend, with a drop on the southwest side. Thus the main deposit may be continuous to the west beyond the limits of present development, with allowance for offsets of this character. The deposit probably has not yet been explored in this direction.

Both tincal and kernite constitute the "ore" of the Baker mine. It appears that the original bedded tincal like that of the Suckow mine

is well represented in many places in the Baker mine, and may be the form in which much of the output is mined. However, there is a great deal of kernite in the deposit. Excellent faces may be found showing bluntly terminated pyramidal and prismatic crystals of kernite, obviously introduced into otherwise regularly bedded tincal and shale, the kernite seemingly disrupting the arrangement of the bedding in the shale. It seems clear that the kernite is secondary to the bedded tincal, but is also altered to a later regeneration of tincal in places, especially as seen in zonal envelopes surrounding and retaining the outer forms of individual kernite crystals.

Suckow Colemanite Mine

The site of the original Suckow discovery well is near the middle of the NW¼ sec. 22, T. 11 N., R. 8 W., S.B. This location is now marked by a rectangular concrete water tank standing on the surface of the ground about 80 feet northwest of a 12-inch pipe or well casing that projects 5 feet above the ground, and a pit near the pipe in which a pump had evidently been installed at some time. A shaft 60 feet N. 77° E. from the well was sunk to test the discovery of colemanite in the well, but apparently was abandoned at a depth of 50 or 60 feet. It shows chiefly granitic gravel and sand on the dump, containing a minor mixture of rounded pebbles of black lava, the whole doubtless from the surface alluvial cover called "overburden."

The record of the discovery of colemanite in section 22 is reviewed, in the detail that was available, in two earlier reports on the Kramer district (Gale, H. S., 26; Noble, L. F., 26) and need not be repeated in full here. Colemanite was encountered at a depth of about 370 feet in the discovery well, in the form of nodules in blue shale, and this occurrence led to extensive prospecting by drilling throughout the general vicinity of the discovery. Some of the early prospects in section 22 are also discussed in the above-mentioned references including the so-called Ulexite shaft, and the Suckow Colemanite mine in section 22 which was then known as Suckow shaft No. 2. The section encountered in this shaft has already been quoted (Gale, H. S., 26, pl. 4); for further details concerning the work done in this area, reference may be made to the works cited (Gale, H. S., 26; Noble, L. F., 26).

Miscellaneous Prospects

Drill Holes Around Border of Main Deposit. Early in the campaign of exploration in the Kramer district, W. S. Russell drilled a well in the northeast corner of section 21, encountering green shale at 120 feet and colemanite-bearing shale between 130 feet and 180 feet. The quantity of colemanite could not be determined. This is the farthest west that a significant showing of borates has been authentically reported. Schaller (36, pl. 1, opp. p. 98) maps two wells in that corner of the section that contained borates. Russell thought he was drilling in section 16, but when he discovered where the section corner was he moved over into section 16 and started another well. Before he could get down to the borate horizon, the borax company bought out his interest in the property, and no further work was done.

Northeasterly Extension of Field. The borax company has drilled a considerable number of holes in the colemanite-ulexite area of sec. 18, T. 11 N., R. 7 W., S.B., carrying northward and eastward the record of hole 61, which is just across the line in section 13 to the west. Drill hole 62, in the southwest corner of the NW¼ sec. 18, showed green shale from

138 feet to 355 feet, blue shale from there to 442 feet, and blue shale with ulexite from there to the bottom at 471 feet. A quarter of a mile farther north, hole 76 shows no borates and very little shale above the basalt. Eastward, along the southern edge of the NW$\frac{1}{4}$ sec. 18, hole 84 shows about the same units as No. 62, but 30 to 40 feet lower, with gray and green shale changing to blue shale at 400 feet and to shale with colemanite at 468 feet and to basalt at 541 feet. No. 85 shows the same changes at 412 feet, 447 feet, and 497 feet, respectively, but holes 56, 86, and perhaps 88, apparently missed the colemanite bed because they drilled through the Russell fault. Holes 86 to 90 were drilled in the northwest 30 acres of the SE$\frac{1}{4}$ sec. 18 after the Russell prospects had disclosed colemanite. No. 87, located 10 feet south and 205 feet east of the center of the section, encountered the colemanite on the uplifted side of the fault, where it is scattered through the interval betweeen the depths of 63 feet and 80 feet, and the basalt at about 105 feet. Hole 50, in the southwest corner of the southeast quarter of the section, and hole 75, a quarter of a mile farther east, encountered a considerable thickness of blue shale with traces of ulexite just above their bottoms, which were at 384 and 604 feet, respectively.

Russell and his associates now hold the NE$\frac{1}{4}$, the E$\frac{1}{2}$SE$\frac{1}{4}$NW$\frac{1}{4}$, and the N$\frac{1}{2}$NW$\frac{1}{4}$ of section 18. Russell's hole No. 1a and shaft, just northeast of the center of the section, began practically at the surface in soft sandstone of the lake-bed series and encountered colemanite-bearing shales between the depths of 77 feet and 108 feet, and the top of the basalt at 153 feet. The Burnham well, 150 feet N. 75° E. of the shaft, was carried to a depth of 825 feet and encountered various other beds of lava, one beginning at 460 feet and a very heavy one from 676 feet on. Russell's drill hole No. 5, near the southwest corner of the E$\frac{1}{2}$SE$\frac{1}{4}$NW$\frac{1}{4}$, struck the colemanite-bearing section at 478 feet, corresponding to the 447-foot depth at which it was found in the borax company hole 85 and other wells to the west.

From these data and the records of other holes drilled later, it is recognized that a northwest-trending fault, here called the Russell fault, passes very close to the center of the section with a downthrow of about 400 feet vertically to the southwest. As a normal fault, it probably dips also to the southwest, but the close spacing of the drill holes on opposite sides indicates that it must be steep and that there are some irregularities along it. The line of chert seams noted on the surface to the southeast, even before the underground evidence for the fault was disclosed, indicates its continuation in that direction and suggests that it is responsible for the lowering and preservation of the roof pendants of the Amargo group, which end in line with it in the NW$\frac{1}{4}$ sec. 28, T. 11 N., R. 7 W., S.B.

Russell's wells 2, 3, and 4 drilled in a north-south row just west of the center line of section 18 apparently missed the ore bed on account of the fault, but they struck the lava underneath at the higher elevation. The dip of the formation in the upper part of the shaft is to the southwest, as if due to drag on the fault. North and northeast, on the upthrown side of the fault, the formation appears to lie nearly horizontally for a considerable distance. Russell's hole No. 6, just northwest of the southeast corner of the N$\frac{1}{2}$NW$\frac{1}{4}$ of the section, not far from the borax company hole 47, went to a depth of 630 feet but apparently struck only gravel and boulders at the depths where the borates and lavas were to be expected. The borates and lavas may have been cut out there by a stream

channel. His hole No. 7, about an eighth of a mile farther west, struck the lava at 278 feet, overlain by clay, but the presence of borates was not disclosed. Thus the formations may be slightly lower there, even on the upthrown side of the fault, than they are northeast of the center of the section. Other holes near the center of the section in the northeast quarter indicate a slight dip to the east and a disappointing thinning of the borates.

W. M. Balling has drilled several holes in the east half of a 60-acre tract that extends across the top of the SE¼ sec. 18. His No. 2, in the northwest corner of his area, went through 36 feet of colemanite-bearing shale reported as 60 percent colemanite, between 254 feet and 290 feet and entered basalt at 299 feet. His No. 3, near the southern boundary of the area and about an eighth of a mile west of the east boundary of the section, was in colemanite-bearing shale from 443 feet to 462 feet, where the rig broke down and the hole was lost. This is the farthest to the east that borates have been credibly reported. Balling's No. 1 and the borax company's No. 46, in the northeast part of the area, encountered only gravel.

A hole drilled by the Pacific Alkali Company (their No. 1) in the northeast quarter of the section, just across the line northwest of Balling's No. 2, showed only gravels and argillaceous arkose to a depth of 800 feet and then a waxy tan clay to 855 feet, the bottom. Another hole (their No. 10) at the center of the northeast quarter of the section went through similar gravel-bearing alluvial sediments with fragments of basalt down to 905 feet, below which are thin pinkish limestones and horizontally bedded grits, tuffaceous silts, and waxy brown clay to 940 feet, probably belonging to the Rosamond formation. It is difficult to reconcile these holes in the gravels with Balling's No. 2. They may merely have missed the borates and lavas and gone into a thick conglomerate within the Saddleback part of the section, though nothing like it is known elsewhere between the lavas; or, perhaps more likely, the upper part is a Pleistocene channel that cut out the borate and lava section and is filled with young alluvium, while the lower part may be an inter-Saddleback conglomerate; or it may all be a channel deposit of Ricardo-Western Borax conglomerate age.

McGinty Prospects. For several years a camp and one or more drill rigs were kept in operation by a group independent of the main operators in the Kramer district. This work was said to have been financed in part at least by a Mr. Birch of the Birch-Royer Oil Company. The camp was situated near the southeastern corner of sec. 12, T. 11 N., R. 8 W., S.B., where two or more of the holes were drilled. Several holes were put down in the southwestern part of section 8; one or two in sections 7, 11, and 12; and one near the center of section 10. All were along the northern border of the main borate basin; they apparently gave no showings of commercial importance. One of these holes, about 1,000 feet north of the southwest corner of section 8, is said to have penetrated 548 feet of "overburden," mainly unconsolidated sand and gravel, overlying 11 feet of black lava, presumably the top of the Saddleback flows. If this record is correct, the lake beds have been eroded—if they ever extended so far out along this edge of the basin, and the lava flows were covered by alluvial fill, probably of post-borate Tertiary age.

Stuart Chevalier Tests. An interesting test, entirely north of the structural basin in which the borates are known, was drilled by Stuart

Chevalier in the SW¼ sec. 35, T. 31 S., R. 40 E., M.D., in the plain between the hills along the north border of the Kramer district and the mountains around Randsburg and Atolia. Limestone and gypsum are exposed at various places in the bottom of this plain, suggesting that a basin of Tertiary deposition may have existed there. Limestone characteristic of the lower part of the Rosamond section is exposed in an anticlinal ridge at the south side of the plain, as though forming an axis of uplift between this area and the extended Kramer basin.

This hole was extensively cored below the depth of 735 feet, the total depth being approximately 1,750 feet. If the equivalent of the borate-bearing Kramer lake beds was encountered in the Chevalier hole it appears that it must have been in the upper part that was not cored, as most of the material recovered by coring was of Rosamond type, consisting of mixed volcanic sediments and decomposed granitic materials. Light chocolate-brown sandstone and white ashy beds predominate between the depths of 700 and 1,000 feet. These are underlain by 260 feet of tile-red sandstone, grayish in places, including some greenish gray tuff-like clay mixed with arkose or gritty sands of various colors. Red sandstone like that mentioned above was found in some of the drill holes put down in sec. 18, T. 11 N., R. 7 W., S.B., in the Kramer borate basin, where it was considered to be typical Rosamond formation. Below 1,260 feet the Chevalier hole passed through gray clay, perhaps derived from volcanic ash, some arkosic (grit) beds, and a distinct volcanic breccia. It bottomed in dark-brown gumbo-like clay.

Kohler Prospects. During late 1924 and early 1925 a series of three holes was drilled by G. M. Kohler in the NE¼ sec. 20, T. 11 N., R. 8 W., S.B., in an effort to discover a possible western extension of the borate basin which might include the borates. Top of the Saddleback lava was reached in each of these holes at the following depths: 257 feet in No. 1; 335 feet in No. 2; and 240 feet in No. 3. These holes were about 500 feet apart in a line southeast from No. 1, near the location temporarily placed for the Gephart School. The Kohler drilling was followed by another test, possibly for the Pacific Coast Borax Company, situated about 825 feet northeast of the Kohler No. 1 hole. It is said to have reached solid lava at the depth of 250 feet. This suggests a southeasterly dip of the lava and overlying lake-bed shales and clays, except for the step-up of the lava in the Kohler No. 3 hole, which may be due to faulting. Borates, if present, might have been expected in the clays immediately overlying the lavas.

Leopold Holes. Two holes were sunk near the middle of sec. 24, T. 11 N., R. 9 W., S.B., and one or more others still farther west near Leopold camp, all on the west border of the Kramer basin. The first of these holes in section 24, near the southeast corner of the northwest quarter, was sunk in 1935 with a drilling mast rig to a depth of about 900 feet. Various reports recorded the finding of borate in the interval 693-702 depth, in a "dark-blue shale," and a sample, probably from this interval, proved to be basaltic mud (scoria?) with a few specks of ulexite. These reports later seem to have been magnified to "10 feet of solid borax," authority unknown. A second hole, drilled in 1936, 175 feet south a little east from the first, near the northeast corner of the SW¼ sec. 24, was extensively cored from 354 feet to bottom at 955 feet, and a good core description was preserved. The section penetrated consists of

yellow, reddish, and gray sandy beds of various textures, with more or less interbedded shale, showing some practically horizontal bedding, to the depth of approximately 625 feet. Between 625 and 678 feet the section changed to bluish bentonitic clay, and shale with some sandy material. Hard basaltic lava was cut from 679 to 692 feet. Below the lava the coarse sediments are chiefly sandy to the bottom. One sample from the depth of 640 feet was reliably reported to have yielded an analysis of 1.75 percent B_2O_3. Other samples showed a mere trace of boron. Thus there is little doubt that the borate-bearing Kramer lake-bed zone is here represented, but probably does not contain commercial quantities of borates.

Marshall Bond Hole. The core hole drilled in 1940 by R. L. Triplett for Marshall Bond in the SE¼ sec. 19, T. 11 N., R. 8 W., S.B., has already been cited in some detail with reference to the excellent section it gave of the post-borate fanglomerate. The Saddleback lavas were encountered at a depth of 711 feet, and extended to a depth of 753 feet. The hole reached a total depth of 1,063 feet. Beneath the lava are sediments, of which an exceedingly complete section was revealed. These sediments can be grouped into the following units: 122 feet of brownish, gritty beds, tan sandy shale and sands, medium to coarse; 55 feet of greenish gray, turfaceous beds, with some sand, showing more or less lamination of bedding; 53 feet of white to greenish gray volcanic tuff or ash, referred to as the "white ash" section in other holes in this vicinity, and probably the same as that exposed in a series of prospect pits in the SW¼ sec. 7, T. 11 N., R. 8 W., S.B.; greenish to gray shale containing tuff, which grades into scoriaceous basalt at the bottom, where it rests on a surface of hard black basaltic lava. This lava was penetrated for 20 feet before the hole was bottomed. No doubt an extensive section of lavas lies below, namely that represented in the central outcrops of the Stone House Hills. No borates were encountered in this hole.

W. M. Balling Tests. Two holes were put down by W. M. Balling and associates near the southeastern corner of sec. 24, T. 11 N., R. 9 W., S.B. These lie near the Marshall Bond test referred to above, and intermediate between that test and the Leopold tests farther west. They were made subsequent to the others. Starting in August 1940, the first of these was drilled to a total depth of 1,138 feet, where the last core was lost on account of a twist-off of the drill stem, and the hole abandoned. The section probably corresponded in a very general way with that of the Marshall Bond hole, but no lava was recorded. Thus the exact correlation remains in some doubt. A second hole was put down 200 feet N. 34° E. from the first, the first 700 feet being drilled without coring. This was continued to a total depth of 1,400 feet, cored between 700 and 800 feet, and again below 1,100 feet to the bottom. No lava or borates were found in either of these holes. It was thought at the time that the bluish clays could be recognized between 737 and 800 feet in the first hole and 35 to 65 feet higher in the No. 2 hole than in the No. 1. Otherwise there was little if anything that could be used as a check between these two nearby sections, although the formation was of similar character throughout.

Tests South of the Main Borate Basin. A considerable series of exploratory holes has been drilled along the southern border of the known borate basin, ranging through secs. 22, 27, 26, and 25, T. 11 N., R. 8 W., S.B., and farther south near the highway east of Amargo or Boron.

The most interesting of these holes was the one drilled by L. Pruett for Harold S. Moyes, which was about 1,100 feet southeast of the northwest corner of sec. 22, T. 11 N., R. 7 W., S.B. It is said to have reached the depth of 1,600 feet. A successful series of cores was obtained. Some rather extraordinary showings of borate were reported between the depths of 1,125 and 1,360 feet in this hole, but the writer is unable to confirm any of these. The Saddleback lava outcrops three-quarters of a mile north of this hole, with southerly dip, so that it might be assumed that the lake beds extend into this area in position above the lava, although the lava may not extend so far.

Other tests by drilling were without commercial or other significance, so far as known.

ORIGIN OF THE DEPOSITS

In brief, the main factors that apparently led to the accumulation of borates in the Kramer district seem to be about as follows. This subject was discussed in a paper read by the writer before a meeting of the Cordilleran Section of the Geological Society of America, in April 1938 (Gale, H. S., 38).

It is generally accepted that the more concentrated occurrences of boron or borate salts have been brought up from the earth's interior to the surface with gases or waters of magmatic origin, in a volcanic region. At Kramer, it seems obvious from the geological distribution of the deposits in relation to certain lavas that the waters that deposited the borates issued with, or as an aftermath of, the outpouring of the Saddleback basalts. These lavas spread down over the land surfaces of that time into the basin in which the lake deposits containing the borates were later laid down. Volcanic waters probably flowed down through or over these lava beds while the rocks were still hot.

Considering the formation of the main deposit of sodium borate first, it may reasonably be assumed that the volcanic waters referred to above probably evaporated rapidly on exposure to the air, either as they flowed down over sloping rock surfaces, or as they accumulated in pools, or in the lake, that lay in the low part of the Kramer basin. There, because of a preponderance of boron or borate in the emanations of this particular volcanic district, these waters became supersaturated primarily with respect to borax. Spread out with a broad surface exposed to the air, the lake waters may have undergone rapid drop of temperature at times, thereby throwing down borax (tincal), while other salts remained in solution. In all essential respects, this is what has long been done artificially for the separation of borax from hot saturated solutions of mixed salts. This was the old process used in refining borax from the old ''marsh borax'' deposits. It yielded a relatively pure crop of borax, even in the presence of large quantities of other salts in the solution. Thus crystalline borax probably accumulated in the lake at Kramer, building up layer by layer. At Kramer the primary layers of sodium borates are interbedded with minor bands of sediment which were presumably washed into the basin by flood waters flowing down from adjacent land surfaces, during the time the crystallizing process was going on.

This does not explain the origin of the sodium that was required to combine with boron for the formation of borax. It is not wholly necessary to assume that the sodium involved in the process was a primary product derived from magmatic sources. Sodium is present in ground water in most volcanic regions and for combinations in the Kramer deposits it

may have been derived by some exchange reaction from contributions out of surface or ground-water supplies.

Recapitulating, the physical features of the sodium borate deposits at Kramer show that the sodium borate was crystallized primarily out of water solution in the form of native borax or tincal, essentially free of other saline substances. The included layers of mud, silt or other sediments are also evidence of the manner in which it accumulated layer by layer to form the original deposit. Incidentally, it may be noted that one of the thin layers of sediments interbedded with the borate shows distinct ripple marks, indicating wave action in a shallow body of water while the borax was being deposited. Also, an egg, perhaps of a water fowl, was found imbedded in the solid crystalline borax at the Suckow mine.

Kernite, which is a considerable part of the sodium borate deposit in two of the three mines at Kramer, is a replacement of original deposits of bedded tincal. There are three salts which are at times included under the general designation borax, or, more technically, there are three hydrates of sodium tetraborate. These are:

$Na_2B_4O_7.4H_2O$	Kernite
$Na_2B_4O_7.5H_2O$	"Octahedral borax"
$Na_2B_4O_7.10H_2O$	Ordinary or "prismatic borax"

Kernite is the stable form at temperatures above 58°C. (136°F.), octahedral borax is not so definitely restricted by temperature, and ordinary borax forms from solution at temperatures below 58°C. Thus if the water in the lake concentrated while its waters maintained a temperature above 58°C., it may be assumed that kernite might have formed. However, the evidence so far seen in the deposit indicates that the kernite present was formed by some change, perhaps by heating after the deposit was covered by sediments, that took place after the primary sodium borate beds had been formed and were fairly well consolidated. Associated with the mineral kernite is the borate mineral probertite, which has a composition like that of ulexite except that it also has less water of crystallization and forms at a higher temperature.

Minute quantities of realgar and stibnite, and possibly a few grams of pyrite, in association with the kernite, indicate the presence of heat while these minerals were being formed.

Nodular and geodal masses of the calcium borate minerals ulexite and colemanite occupy some of the sedimentary layers that extend beyond the margin of the sodium borate deposit, in a stratigraphic zone that was apparently of origin contemporaneous with the deposition of the primary sodium borate beds, and these two minerals also occur in the blue shale or clay that overlies the main sodium borate deposit. These minerals are in form and occurrence similar to Tertiary deposits at other places in the Mojave-Death Valley region. It is assumed that these borates containing lime may have formed from the same general source as the sodium borates, where the solutions containing boron encountered ground waters or clays containing more calcium than was present in the lake solution. Ulexite is the borate mineral most commonly formed in sediments of the playa type near hot springs that bring up boron. In places colemanite can be recognized as definitely secondary to ulexite, not only in the Kramer district but in other colemanite areas. However, it is not at all certain that colemanite is always secondary to ulexite. Colemanite is found at places in distinct veins filling fissures, as in Death Valley, at the Shoshone deposit, and in Ventura County.

CONCLUSION

As a result of the present understanding of conditions in the Kramer area, based on rather extensive exploration, the general conclusion seems justified that the important borate deposits are confined to a single, relatively local area. This conclusion is not intended to discourage speculative exploration—by drilling or other methods—in the hope of finding a new deposit; but it seems wise to offer warning that the chances of success in the vicinity of the known deposits are probably remote, as concerns any particular project. New projects should be based on an understanding of certain geological features of the area, to preclude needless expenditure for drilling in basement rocks, and through the Rosamond formation, in which only disseminated borates have been found to date, in relatively minor quantities.

Much is, of course, still to be learned about this area. However, until some reasonably significant clue to a new area of deposits is discovered, it will probably be safe to view proposals for exploitation around the borders of the present known deposits with considerable caution.

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SPECIAL ARTICLES

SALT*

THE MOST USEFUL OF MINERAL SUBSTANCES

HISTORIC COMMODITY PLAYS VITAL ROLE IN FOODS, AGRICULTURE AND INDUSTRY

By E. B. Tustin, Jr.**

Salt is the most common mineral in existence, but do you know of any more useful? Since early times salt has been associated with value and worthiness, as witness the Biblical statement, "Ye are the salt of the earth" (Matthew 5:13).

To primitive people salt represented something that was not perishable and that would keep foods from spoiling; hence the sacred significance with which salt was endowed.

We find that whenever sodium chloride is named in the Bible it is done so in language stamping it as a most important essential. Especially do we notice this in directions for religious services. When Elisha sweetened the waters of Jericho he cast salt into them, illustrating the purifying properties of salt, for he said, "I have healed these waters" (II King 11).

Salt as a Covenant

In Eastern countries it is a time-honored custom to place salt before strangers as a token and pledge of friendship and good will.

The antiquity of the practice of using salt in confirmation of an oath is shown in the following passage from an ode of the Greek lyric poet, Archilochus, who lived 2,000 years ago:

"Thou hast broken the solemn oath
And hast disgraced the salt and the table."

Even at the present time, Arabian princes are wont to ratify an alliance by sprinkling salt upon bread, exclaiming, "I am the friend of thy friends, and the enemy of thine enemies."

During the Indian mutiny of 1857 a chief motive of self-restraint among the Sepoys was the fact that they had sworn by their salt to be loyal to the English Queen.

Salt Superstitions

The widespread notion that the spilling of salt produces evil consequences was probably due to the sacred character of salt in early times. Anyone having the misfortune to spill salt was supposed to incur the anger of all good spirits. Leonardo da Vinci evidently had this superstition in mind when he portrayed an overturned salt cellar before Judas in the painting, "The Last Supper."

* Reprinted from May-June 1946, issue of *Flow Line*, by permission of Rockwell Manufacturing Company, Pittsburgh, Pennsylvania.
** Worcester Salt Company, New York City.

Through the ages belief in the sacred properties of salt persisted. In Scotland salt was in high repute as a charm, and the salt box was the first chattel to be removed to a new dwelling. When Robert Burns, in 1789, was about to occupy a new house at Ellisland, he was escorted on his route along the banks of the River Nith by a procession of relatives, and in their midst was carried a bowl of salt resting on the family Bible. Peculiar notions about the magical properties of salt were common among uneducated people in this country. In some regions a new tenant would not move into a furnished house until all the objects therein had been thoroughly salted, with a view to the destruction of witch-germs.

Salt Used as Money

Roman soldiers received part of their pay in the form of salt, from which comes our modern word ''salary'' and the expression ''worth his salt.''

Among the old Chinese, salt was considered second in value to gold only, and it held an important place in the monetary system of the Great Moguls. Marco Polo, in the 13th Century, writes of flat cakes of salt, bearing the stamp of the Great Khan, which were used as money in Tibet. Even today salt takes the place of money in certain parts of Africa, Mexico and the South Sea Islands. When the followers of Mussolini invaded Ethiopia, the native hunters refused to accept Italian currency in exchange for skins, but instead, used coin-shaped discs of salt. Right here in America, each member of the Onondaga tribe of Indians receives from New York State an annual payment of salt, in accordance with an old treaty, as part compensation for ceding 7,300 acres of land in 1813.

The Salt Cellar

The Romans considered salt to be a sacred article of food, and it was a matter of religious principle with them to see that no other dish was placed upon the table before the salt was in position. With the peasant, a shell served as a receptacle for salt, but at the repast of the wealthy citizen a silver salt cellar, which was usually an heirloom, was placed in the middle of the table, and this custom prevailed in England in early times. Medieval salt cellars were often elaborate pieces of craftsmanship. Until the end of the 17th Century, the rank of guests at a banquet was indicated by their seating with reference to the massive silver salt cellar. At the head of the table ''above the salt'' sat the host and his more distinguished guests. The less noble sat ''below the salt.'' In the 11th Century the laws of King Canute provided that any person sitting at a banquet above the position to which he was entitled should be ''pelted out of his place by bones at the discretion of the company.'' Those were days of meat in abundance.

Salt in Warfare

A strategic part has been played by salt in great military engagements. Napoleon's soldiers on the celebrated retreat from Moscow died by thousands as the result of wounds whose failure to heal was attributed to prolonged deprivation of salt. The same circumstances were reported during the Paraguayan War of 1874. In our own country during the Civil War, one of the principal purposes of a Union campaign into Virginia was to capture the chief source of salt of the Confederacy located at Saltville. Nowadays salt plays an important new part with the armed forces as well as in civilian industry. Millions of salt tablets are used to replace salt lost through perspiration and thus help ward off fatigue.

History is filled with illustrations of the economic pressure exerted on people by lack of salt. It has forced them to make war, build ships, roads and cities, and enter into commerce on land and sea.

How Salt Is Obtained

Old manuscripts reveal that 5,000 years ago in China salt was obtained by boiling and evaporating the ash from sea weeds. In America scarcely 100 years ago Indian tribes, situated near the ocean, evaporated sea water in open trenches. Those inland obtained salt by boiling and evaporating the brine from salt springs to which buffalo and deer were wont to come.

Early American settlers, living in the interior, experienced great perils and hardships to obtain salt. As might be imagined, salt was expensive and at the time of the War of 1812, it cost $5.00 a bushel.

Little change was made in the method of salt manufacture through the ages until 1886, when Joseph Duncan, an American, started a salt company at Silver Springs, New York. He employed a revolutionary new process—the vacuum pan process—that is in use today, producing fine salt or table salt, which comes in familiar cartons. This method produces a uniformly grained salt of very high purity.

At the Silver Springs plant of the Worcester Salt Company, four 22-foot vacuum pans form a quadruple effect unit.

Valves at Silver Springs

Wells are bored and water is piped down to salt strata in the earth. The resulting brine which has been pumped up from the wells, and purified is fed into each of four pans through a 2″ Nordstrom valve. This valve has an extended handle to the floor above where the vacuum pan operator is stationed.

Inside the vacuum pans the water is evaporated from the brine, leaving the salt crystals which drop to the bottom of the pan legs. At this point fresh brine is jetted into the leg under pressure to form a slurry of salt and brine and the mixture flows through another 2″ valve into a pump tank. The 4″ valve at the bottom is located on the "lump line" and it is used periodically to remove lumps which accumulate in the bottom of the pan leg.

From the pump tank as the name implies, the slurry is transferred by pumps equipped with Nordstrom valves, through a special rubber hose to the separation tank. Here the excess brine is overflowed, along with some impurities, and the salt drops to the bottom of the tank. Again jet brine is forced in with the salt to form a slurry, and this flows by gravity through one of the twin 2″ valves into the feed box of the 6-foot diameter by 4-foot face rotary filter.

The feed box spreads the salt slurry evenly across the filter screen, and since the screen is under vacuum the brine is very quickly pulled through, leaving a cake of salt. The vacuum continues to remove moisture and further along in the cycle pulls hot air through the cake to completely dry it. The dried salt is scraped from the screen and after passing over a steel belt is discharged into a rotary dryer where it is actually cooled.

Separating Salt Grades

From the dryers the salt is elevated and passed over screens which separate the various grades of fine salt. The high grade is mixed auto-

matically to form free flowing or iodized salt as required, and passes through a system of screw conveyors to the filling machine bins.

The filling machines automatically weigh and fill about fifty 2-lb. or 26-oz. round containers per minute. The containers are automatically packed twenty-four to a case and the case is automatically glued and sealed.

Widespread Uses for Salt

The more civilization has progressed the more demand there has been for salt, and today over 4,000,000 tons of evaporated salt are required annually for the home and for a vast number of farm and industrial uses. In the curing of hides and skins for leather, 300,000 tons of salt are used yearly. In discovering rayon, a blow was struck at the Japanese silk industry. Rayon is manufactured by means of caustic soda, which is obtained from salt.

According to Dr. Morris Fishbein, Editor of the Journal of the American Medical Association and Hygeia: "Sodium chloride or common salt probably ranks first among all the salts in the human body, both in quantity and in its value in the body's nutrition."

Nutritionists estimate that adults require about one-half ounce of salt per day, or 12 pounds per year, to enable the various glands to hold the amount of water they need for proper functioning. Salt is also the source of an important component of gastric juice, both in the human and animal body. Upon receiving salt, the stomach changes its chloride component into hydrochloric acid in order to digest food. The body divides the salt into its chemical constituents with the greatest of ease, but it takes elaborate equipment to do the same thing industrially.

Electricity is the key to the decomposition of the salt crystal. When a strong current is passed through molten salt, the hot mass is separated into a silvery white metal, sodium, and the greenish yellow gas, chlorine.

Both elements are widely used by industry. Sodium has been employed for many years in the manufacture of dyes, insecticides and photographic materials, and more recently in making the tetraethyl lead used in aviation gasoline. Operation of airplanes at terrific speeds necessary during the war was also facilitated by the use of sodium in the valve stems. By this means, heat from the engine is conducted rapidly to the radiating system and danger of overheating is minimized.

Molten Salt for Hardening

The wearing parts of tanks, trucks and planes could not have taken the terrific punishment to which they were subjected if the pinions and gear surfaces had not been "case hardened" in a bath containing molten sodium cyanide, another member of the salt family.

Likewise from salt comes sodium peroxide, with which millions of yards of cotton fabrics are bleached.

Chlorine, the other element derived from salt, is equally versatile. Added to drinking water in small quantities, it has saved thousands of lives by destroying bacteria.

Salt is extensively used in the production of chemicals for plastics.

From hydrochloric acid, another salt derivative, and acetylene gas comes neoprene synthetic rubber, referred to by the Baruch Committee as the "one synthetic material of a quality to be the full equivalent of natural rubber for combat and heavy duty tires." Neoprene is also used to coat fabrics for blimps. Other salt-derived products, the chlorinated

hydrocarbons, are required in enormous quantities to clean the metal parts going into tanks, trucks, ships, planes and guns, And one of these compounds was used in making smoke screens to conceal the movements of the United States forces. Other chlorine compounds include fire-extinguisher fluids, refrigerants, and anesthetics.

In the home, salt solutions have long been used as a gargle, and salt is an important constituent of some dentifrices. Chemicals from salt are now needed to make the new ''sulfa'' drugs, vitamins, and other pharmaceuticals.

MINERAL EXHIBIT AND STATISTICS

ACCESSIONS TO THE EXHIBIT

By Henry H. Symons *

The museum of the State Division of Mines possesses an exceptionally fine collection of rocks and minerals of economic and academic value. It ranks among the first five such collections in North America and contains not only specimens of most of the known minerals found in California, but much valuable and interesting material from other states and foreign countries as well.

The exhibit is daily visited by engineers, students, business men and prospectors as well as tourists and sightseers. In addition to its practical use in the economic development of California's mineral resources, the collection is a most valuable educational asset to the state and to San Francisco.

Mineral specimens suitable for exhibit purposes are solicited, and their donation will be appreciated by the Division of Mines, as well as by those who utilize the facilities of the collection.

Among the specimens received recently and catalogued for the exhibit are the following:

21229 BORNITE (Cu_5FeS_4), a copper-iron sulphide. From Magma Copper Company, Superior, Arizona. Donor: Charles Cox, May 1946. Case 303.

21230 MAGNESITE ($MgCO_3$). Being used commercially by Westvaco Chlorine Products Company, at Newark, California, for "caustic" magnesia. From Luning, Nevada. Donor: Walter W. Bradley, May 1946. Case 407.

21231 Artificial PERICLASE (MgO). Produced from sea-water magnesia. From Westvaco Chlorine Products Company, Newark, California. Donor: Walter W. Bradley, May 1946. Case 802.

21232 Barkevikite SYENITE. From San Benito River near Gem mine, sec. 25, T. 15 S., R. 12 E., San Benito County, California. Donor: R. A. Crippen, May 1946. Case 501.

21233 CINNABAR (HgS). Has well-formed translucent crystals. From Patricks Creek mine, Del Norte County, California. Donor: Oscar E. Hanno, June 1946. Case 107.

21234 AZURITE in limonite-stained QUARTZ from Siskiyou County, California. Donor: Tom Miller, June 1946. Case 233.

21235 Native COPPER (Cu) crystals from Siskiyou County, California. Donor: Tom Miller, June 1946. Case 233.

21236 Phenocryst in PUMICE. Near Mono Lake, Mono County, California. Donor: Joe Scanavino, June 1946. Case 503.

21237 CHRYSOCOLLA ($CuSiO_3.2H_2O$), a hydrous copper metasilicate from Contact, Nevada. Donors: Charles B. Foster and Boyd Wood, July 1946. Case 139.

21238 MARMATITE (FeS-ZnS), a ferriferous sphalerite, with CHALCOPYRITE. From Mattie orebody of Mountain Copper Company's Hornet mine, Matheson, Shasta County, California. Donor: Walter W. Bradley, August 1946. Case 106.

21239 CHROMITE, high-grade, from Gray Pit lease of McLaughlin-Applegarth, Tehama County. Donor: Walter W. Bradley, August 1946. Case 235.

21240 Banded disseminated CHROMITE from McLaughlin-Applegarth lease on school land, west of Red Bluff, on North Fork of Elder Creek, Tehama County, California. Donor: Walter W. Bradley, August 1946. Case 235.

* Statistician and Curator, Division of Mines.

21241 CHALCOPYRITE. From Gray Eagle copper mine, Siskiyou County, California. Donor: Walter W. Bradley, August 1946. Case 233.

21242 Iron Ore, HEMATITE—LIMONITE, from Vulcan iron mine, Kelso, San Bernardino County, California. Donor: Walter W. Bradley, August 1946. Case 226.

21243 CASSITERITE (SnO_2) in calcite. From Evening Star mine near Cima, San Bernardino County, California. Donor: Walter W. Bradley, August 1946. Case 226.

21244 MANGANESE ORE from Staneuch Mines, San Luis Obispo County, California. Donor: Walter W. Bradley, August 1946. Case 228.

21245 CHROMITE ($FeO.Cr_2O_3$) high-grade. From French Hill mine, Del Norte County, California. Donor: Walter W. Bradley, August 1946. Case 205.

21246 SILVER-GOLD ORE from Palisade mine near Calistoga, Napa County, California. Donor: Walter W. Bradley, August 1946. Case 218.

21247 CINNABAR (HgS) in calcite, from sec. 31, T. 18 S., R. 5 E., M. D., Monterey County, California. Donor: Walter W. Bradley, August 1946. Case 218.

21248 Lava (vitrophyre phase) from Lake Abert, Lake County, Oregon. Donor: Walter W. Bradley, August 1946. Case 503.

21249 STIBNITE with gold and silver, from Oro y Plata mine, near Murphys, Calaveras County. Donor: Walter W. Bradley, August 1946. Case 204.

21250 GRANODIORITE from Lower Minaret Creek, Madera County. Donor: Walter W. Bradley, August 1946. Case 501.

21251 GRANODIORITE with coarse feldspar crystals, from upper Middle Fork of Stanislaus River, on Sonora Pass road, California. Donor: Walter W. Bradley, August 1946. Case 501.

21252 GRANITE PORPHYRY with large FELDSPAR crystals from above Tenaya Lake, Yosemite National Park. Donor: Walter W. Bradley, August 1946. Case 501.

21253 ANDESITE old lava (prior to 1914 eruption) showing both fine- and coarse-grained phases from top of Lassen Peak. Donor: Walter W. Bradley, August 1946. Case 503.

21254 PUMICE (1915 eruption) from devastated area northeast side of Lassen Peak. Donor: Walter W. Bradley, August 1946. Case 503.

21255 VITROPHYRE, spongy phase from throat of crater of 1915 eruption, Lassen Peak. Donor: Walter W. Bradley, August 1946. Case 503.

21256 VITROPHYRE (1915 eruption) altered by fumarole action in crater of Lassen Peak, since eruption. Donor: Walter W. Bradley, August 1946. Case 503.

21257 Native ARSENIC in quartz. From Alcalde mine west of Grass Valley, Nevada County. Donor: Lloyd L. Root, August 1946. Case 212.

21258 ROSE QUARTZ. Cut specimen shows asterism. Near Chilcoot on Plumas-Lassen County line. Donor: Harry E. Chaffee, August 1946. Cases 617 and 222.

21259 TANTALITE-COLUMBITE in LEPIDOLITE from near Gunnison, Colorado. Donor: P. D. Burtt, August 1946. Case 140.

21260 SPHALERITE, rich in cadmium and rare metals, such as germanium, indium, etc. Specimen fluoresces and is triboluminescent. From Plomositas mine near Pichacos, Chihuahua, Mexico.

21261 SHATTUCKITE ($2CuSiO_3.H_2O$). From New Cornelia mine, Ajo, Arizona. Donor: C. E. Bronson, August 1946. Case 139.

21262 ANGLESITE ($PbSO_4$) associated with galena and cerussite. Found at Darwin Mines of Anaconda Mining Company, Darwin, Inyo County, California. Donor: Anaconda Mining Company, Darwin, California, August 1946. Case 147.

21263 GALENA in STRONTIANITE. Found on property of Rex Mining Company, Mesquite Mining District, Virgin Mountains, Mohave County, Arizona. Donor: John C. P. Skottowe, August 1946. Case 307.

CALIFORNIA MINERAL PRODUCTION FOR 1945

By Henry H. Symons *

Tabulations are presented herein showing the complete totals for all substances produced in California during the year 1945, grouped by substances and by counties. The complete detailed annual report on the mineral production of California for 1945 will be available later as Bulletin 137 of the State Division of Mines.

The total value of mineral output in California for the year 1945 was $473,661,591, an increase of $3,887,066 over the 1944 total, which was $469,774,525. The increase was due to the unprecedented output of petroleum and natural gas. There were 58 different mineral substances, exclusive of the various stones grouped under gems, on the commercial list; and all 58 counties of the state contributed.

The salient features of 1945 mineral production, as compared with the previous year, were: The only group that showed an increase in total value was fuels; this total value was the largest on record. Mineral substances showing the greatest annual output as to amount and value were barite, diatomite, gypsum, lithium minerals, natural gas, silica (quartz and glass sand), soapstone, talc and pyrophyllite, and soda (soda ash and salt cake). Petroleum registered its greatest annual yield and zinc the largest annual value.

Of the fuels, petroleum production increased from 311,717,804 barrels worth $330,659,802 in 1944, to 328,262,400 barrels valued at $342,756,767 in 1945, an increase of 5.3 percent in amount and 3.66 percent in value. The 1945 output of crude oil was the largest on record but was exceeded in value by that of 1926 when the value per barrel was $1.538 compared with $1.044 in 1945. Natural gas increased from 467,743,258 M cubic feet worth $31,797,418 in 1944 to 538,273,934 M cubic feet valued at $35,362,313, which was the largest annual yield ever reported in the state.

Of the metals, an increase in annual value was recorded for gold, lead, silver, and zinc; all others showed a decline in amount and value from 1944. The value of the gold yield increased from $4,108,055 in 1944 to $5,177,830 and again passed all metals in point of value, having been passed by tungsten ore and quicksilver during the war years. Copper decreased from 25,584,865 pounds worth $3,453,957 to 13,949,675 pounds worth $1,883,206. Lead increased from 11,408,381 pounds worth $912,670 to 14,504,767 pounds worth $1,247,410. This output was only exceeded by that of 1917. Quicksilver decreased from 28,097 flasks worth $3,178,969 to 21,062 flasks worth $2,697,835. Tungsten ore decreased from 203,965 units worth $4,835,810 to 71,511 units worth $1,587,951. Zinc increased from 16,456,103 pounds worth $1,875,996 to 19,340,732 pounds worth $2,224,184, which was the largest annual value of this metal.

The industrial non-metallic group as a whole decreased from $62,292,574 in 1944 to $59,695,692, which was chifly due to miscellaneous stone, whose total value decreased from $25,138,003 to $20,207,351. Most other important minerals under this classification—such as bentonite, cement, pottery clay, diatomite, lithium minerals, pumice and volcanic ash, and talc and soapstone—registered gains in total value. Cement, most

* Statistician and Curator, Division of Mines.

important material in this group, increased from 14,599,752 barrels worth $21,249,520 in 1944 to 15,922,772 barrels worth $23,469,027.

The saline group decreased from $20,983,104 in 1944 to $18,918,432 in 1945, but the 1944 total included a considerable amount of magnesia produced before 1944 but not previously reported. Increased outputs were reported for borates, potash and soda; all other substances showed a decline.

Distribution by counties for 1945

County	Value	Number of mineral products	County	Value	Number of mineral products
Alameda	$6,661,939	10	Placer	$241,359	10
Alpine	1,500	1	Plumas	41,243	6
Amador	487,544	8	Riverside	4,644,406	12
Butte	663,610	8	Sacramento	9,240,880	9
Calaveras	2,789,881	10	San Benito	1,949,386	5
Colusa	7,083	1	San Bernardino	23,038,011	29
Contra Costa	2,496,533	9	San Diego	1,142,350	11
Del Norte	341,306	4	San Francisco	75,172	2
El Dorado	301,627	10	San Joaquin	1,256,594	8
Fresno	51,677,246	12	San Luis Obispo	497,923	7
Glenn	72,046	2	San Mateo	2,363,508	5
Humboldt	201,514	7	Santa Barbara	22,643,580	7
Imperial	383,431	8	Santa Clara	5,810,388	10
Inyo	4,258,250	15	Santa Cruz	2,015,407	8
Kern	126,716,070	18	Shasta	2,119,802	12
Kings	13,568,174	3	Sierra	172,782	3
Lake	197,448	3	Siskiyou	926,305	10
Lassen	20,635	3	Solano	5,282,725	2
Los Angeles	103,641,827	12	Sonoma	807,122	5
Madera	189,886	7	Stanislaus	406,727	6
Marin	491,435	5	Sutter	62,910	2
Mariposa	1,171,094	7	Tehama	69,921	2
Mendocino	118,767	4	Trinity	91,560	7
Merced	285,363	4	Tulare	256,764	3
Modoc	193,156	5	Tuolumne	434,626	8
Mono	91,928	10	Ventura	29,352,740	8
Monterey	3,018,280	8	Yolo	479,810	4
Napa	628,974	7	Yuba	1,186,139	5
Nevada	1,196,433	5			
Orange	35,178,471	11	Total value	$473,661,591	

Distribution of 1945 output by substances

Substance	Amount	Value	Number of properties
Borates	257,299 tons	$5,898,823	5
Brick and hollow tile	------	3,523,661	27
Cement	15,922,772 bbls.	23,469,027	11
Chromite	9,784 long tons	431,445	34
Clay (pottery)	497,586 tons	1,345,966	40
Copper	13,949,675 lbs.	1,883,206	[e]
Gold	147,938 fine ozs.	5,177,830	[a]
Granite	------	220,411	10
Gypsum	442,133 tons	954,696	7
Iron ore	240,917 tons	883,434	4
Lead	14,504,767 lbs.	1,247,410	[e]
Limestone	532,480 tons	1,626,844	22
Manganese ore	1,875 long tons	86,270	13
Mineral water	26,502,875 gallons	798,430	28
Natural gas	538,273,934 M. cu. ft.	35,362,313	[b]
Petroleum	328,262,400 bbls.	342,756,767	[b]
Platinum group metals	145 fine ozs.	6,719	[e]
Pumice and volcanic ash	89,209 tons	461,022	18
Quicksilver	21,062 flasks	2,697,835	43
Salt	734,736 tons	2,030,226	11
Sandstone	------	7,498	4
Silica (glass sand and quartz)	581,725 tons	1,309,564	6
Silver	986,998 fine ozs.	701,723	[a]
Soapstone, talc, and pyrophyllite	65,202 tons	922,682	13
Soda (saltcake and soda ash)	311,236 tons	3,793,571	4
Stone, miscellaneous	29,449,484 tons [c]	20,207,351	315
Tungsten ore	71,511 units	1,587,951	9
Zinc	19,340,732 lbs.	2,224,184	[e]
Unapportioned [d]	------	12,044,732	
Total value		$473,661,591	

[a] There were 87 lode mines and 99 placer mines, not including snipers, prospectors, and various individuals who sold small lots.

[b] There was an average of 22,162 producing wells.

[c] Includes macadam, crushed rock, ballast, rubble, riprap, sand and gravel.

[d] Includes asbestos (2), barite (3), bentonite (3), bituminous rock (1), bromine (3), calcium chloride (1), carbon dioxide (2), coal (1), diatomite (4), dolomite (3), feldspar (1), garnets (abrasive) (1), gems (2), iodine (2), lithia (1), magnesite (1), magnesia (6), mica (sericite) (1), mineral paint (1), potash (1), pyrite (1), sillimanite group (2), slate (2), strontium minerals (2), tube mill pebbles (1).

[e] Included with gold.

LIBRARY

LIBRARY REPORT

By Roy Nielsen *

OUTLINE OF REPORT

INTRODUCTION

The library of the Division of Mines is at present being reorganized for improved service to its users. Effective as of September 16, 1946, Mr. Roy Nielsen was appointed Librarian. Mr. Nielsen is a trained librarian and geologist who plans to build up the library in every department.

The library now consists of over 7,000 selected volumes on mines, mining, minerals, geology, and allied subjects in addition to large collections of depository copies of reports and bulletins of technical departments of federal and state governments and educational institutions both domestic and foreign. Current copies of newspapers from many California mining towns are available for reference in our Reading Room. Both the Library and Reading Room are open to the public during the usual office hours, when the librarian may be freely called upon for all necessary assistance.

* Librarian, California State Division of Mines.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY AND UNITED STATES BUREAU OF MINES

The library of the Division of Mines has available for public reference the following publications of the United States Geological Survey: Annual Reports, Monographs, Professional Papers, Bulletins, Water-Supply Papers, Mineral Resources, Folios of the Geologic Atlas of the United States (broken file), Maps with Descriptive Text (broken file), Administrative Publications (broken file); and the following publications of the United States Bureau of Mines: Bulletins, Technical Papers, Economic Papers (broken file), Mineral Resources of the United States, Monographs (broken file), Reports of Investigations, Information Circulars.

PUBLICATIONS OF STATE SURVEYS

A broken file of mining and geological publications, issued by the organizations listed below, may be consulted in the library of the Division of Mines.

Alabama Geological Survey, University.
Alaska (Territorial Commissioner of Mines), Juneau.
Arizona Bureau of Mines, Tucson.
Arkansas Geological Survey, Little Rock.
Colorado Bureau of Mines, Denver.
Connecticut Geological and Natural History Survey, Hartford.
Florida Department of Conservation, Tallahassee.
Georgia Division of Geology, Atlanta.
Idaho Bureau of Mines and Geology, Moscow.
Illinois Geological Survey, Urbana.
Indiana Division of Geology, Indianapolis.
Iowa Geological Survey, Des Moines.
State Geological Survey of Kansas, Lawrence.
Kentucky Geological Survey, Frankfort.
Louisiana Department of Conservation, New Orleans.
Maine State Geologist, Augusta.
Maryland Geological Survey, Baltimore.
Michigan Geological Survey, Lansing.
Minnesota Geological Survey, Minneapolis.
Mississippi State Geological Survey, University.
Missouri Bureau of Geology and Mines, Rolla.
Montana Bureau of Mines and Geology, Butte.
Nebraska Geological Survey, Lincoln.
Nevada State Bureau of Mines, Reno.
New Jersey Department of Conservation and Development, Trenton.
New Mexico Bureau of Mines and Mineral Resources, Socorro.
New York Science Division, Albany.
North Carolina Geological and Economic Survey, Chapel Hill.
North Dakota Geological Survey, Grand Forks.
Ohio Geological Survey, Columbus.
Oklahoma Geological Survey, Norman.
Oregon State Department of Geology and Mineral Industries, Portland.
Pennsylvania Topographic and Geological Survey, Harrisburg.
South Dakota State Geological Survey, Vermillion.
Tennessee Division of Geology, Nashville.
Texas Bureau of Economic Geology, Austin.
Virginia Geological Survey, University.
Washington State Department of Conservation and Development, Pullman.
West Virginia Geological Survey, Morgantown.
Wisconsin Geological and Natural History Survey, Madison.
Wyoming Geological Survey, Cheyenne.

PUBLICATIONS OF FOREIGN GOVERNMENTS

Publications of the following departments of foreign governments are received and current issues may be consulted in the library. Earlier issues of foreign-language publications have been loaned to the California Academy of Sciences in Golden Gate Park, because of the limited storage space at the Divisions' offices in the Ferry Building. They may, however, be consulted at the Academy.

Alberta Research Council, Edmonton.
Argentina Direccion General de Minas y Geologica, Buenos Aires.
Brazil, Divisao de Geologica e Mineralogie, Rio de Janeiro.
Brazil, Ministry of Foreign Affairs, Rio de Janeiro.
Department of Scientific and Industrial Research, Wellington, N. Z.
Federated Malay States, Geological Survey, Kuala Lumpur.
Geological Service of Mines Geraes, Harizonte, Brazil.
British Columbia Minister of Mines, Victoria.
British Museum and Natural History, London.
Canada Department of Mines, Ottawa.
Cuerpo de Ingenieros de Minas del Peru, Lima.
Geological Survey of Scotland.
Geological Survey, West Australia, Perth.
Gouvernment General de L'Afrique Equitoriale Francaise, Service des Mines, Brazzaville.
Gouvernment General de L'Afrique Occidentale Francaise, Service des Mines, Dakar.
Instituto Historica e Geographico, Rio de Janeiro.
Mexico, Universidad Nacional Autonoma de Mexico, D. F.
Ministerio da Agricultura, Divisao de Geologia e Mineralogia, Rio de Janeiro.
Ministerio de Agriculturo, Direccion de Minas y Geologia, Buenos Aires, Argentina.
Ministerio de Fomento y Obras Publicas, Lima, Peru.
Museo de Historia Natural de Montevideo, Uruguay.
Museu Nacional, Rio de Janeiro, Brazil.
New South Wales Department of Mines, Sydney, Australia.
New Zealand Geological Survey Branch, Wellington.
Nova Scotia Department of Public Works and Mines, Halifax.
Ontario Department of Mines, Toronto, Canada.
Quebec Bureau of Mines, Quebec.
Queensland Department of Mines, Brisbane, Australia.
Queensland Government Mining Journal, Brisbane.
Republica Argentina, Direccion de Minas, Geologia, e Hidrogeologia, Buenos Aires.
Royal Society of South Australia, Department of Mines, Adelaide.
Secretaria de la Economia Nacional, Direccion General de Minas, y Petroleo, Mexico, D. F.
South Australia Department of Mines, Adelaide.
Universidad Nacional de Tucuman, Tucuman, Argentina.
Victoria, Department of Mines, Melbourne, Australia.
Western Australia Geological Survey, Perth.

PUBLICATIONS OF DOMESTIC SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academy of Natural Sciences of Philadelphia.
American Association of Petroleum Geologists, Tulsa, Oklahoma.
American Geographical Society of New York.
American Institute of Mining and Metallurgical Engineers, New York.
American Journal of Science, New Haven, Conn.
American Society of Civil Engineers.
California Academy of Sciences, San Francisco.
Carnegie Institution of Washington.
Cleveland Museum of Natural History, Cleveland, Ohio.
Colorado College, Colorado Springs.
Colorado School of Mines, Golden.
Colorado Scientific Society, Denver.
Commonwealth Club, San Francisco.
Economic Geology, Lancaster, Pennsylvania.
Field Museum of Natural History, Chicago.
Franklin Institute, Lancaster, Pennsylvania.
Geological Society of America, Baltimore.
Journal of Geology, Chicago.
Journal of Poleontology, Chicago.
Mineralogical Society of America, Menasha, Wisconsin.
Michigan College of Mining and Technology, Houghton.
Mining and Metallurgical Society of America, New York.
Missouri School of Mines and Metallurgy, Rolla.
National Research Council, Washington, D. C.
National Speleological Society, Washington, D. C.
New York Academy of Sciences, New York.
New York State Museum, Albany.
Pennsylvania State College, State College.
Seismological Society of America, Stanford University.
San Diego Society of Natural History, San Diego, California.
Santa Barbara Museum of Natural History, Santa Barbara, California.
Sierra Club, San Francisco.
Southern California Academy of Sciences, Los Angeles.
Stanford University, Palo Alto, California.
University of California Publications in Engineering, Geography, and Geology, Berkeley.
University of Harvard, Department of Mineralogy and Petrography, Cambridge, Mass.

PUBLICATIONS OF FOREIGN SOCIETIES AND EDUCATIONAL INSTITUTIONS

Academia de Ciencias y Artes de Barcelona, Spain.
Australian Museum, Sydney.
Canadian Institute of Mining and Metallurgy, Montreal.
Chamber of Mines of West Australia, Kalgoorlie.
Geological Society of London.
Institution of Mining and Metallurgy, London.
Instituto Geologica de Mexico, Mexico, D. F.
Journal of the Royal College of Science, London.
Mexico Journal, Compilation and Translation Department, San Antonio, Texas.
Philippine Journal of Science, Manila.
Royal Society of South Australia, Adelaide.
Transvaal Chamber of Mines, Johannesburg.

CURRENT MAGAZINES

Current issues of the technical magazines listed below are on file in the reading room of the library, and may be consulted.

A.D.T. Transmitted, New York.
Asbestos, Philadelphia.
Bakelite Review, New York.
Brick and Clay Record, Chicago.
California Highways and Public Works, Sacramento.
California Magazine of the Pacific, San Francisco.
California Mining Journal, Auburn.
California Oil World, Los Angeles.
California Safety News, San Francisco.
Canadian Mining Journal, Gardenvale, Quebec.
Chemical and Metallurgical Engineering, New York City.
Chemical Engineering and Mining Review, Melbourne, Australia.
Chemical Industries, Philadelphia.
Deco Trefoil, Denver.
Desert Magazine, El Centro.
Du Pont Magazine, Wilmington, Del.
Driller, South Milwaukee.
Engineering and Mining Journal, New York.
Fairbanks-Morse News, Chicago.
Foote Prints, Philadelphia.
Fusion Facts, Whittier, California.
Gemmologist, London.
Grizzly Bear, Los Angeles.
Hercules Mixer, Wilmington, Delaware.
Highway Magazine, Middletown, Ohio.
Highway Traveller, Cleveland.
Independent Monthly, Tulsa, Oklahoma.
Johnson National Distillers Journal, St. Paul.
Light, Cleveland.
Light Metal Age, Chicago.
Lubrication, The Texas Co., New York City.
Marion Groundhog, Marion, Ohio.
Metals and Alloys, Pittsburgh, Pennsylvania.
Mineralogist, Portland, Oregon.
Mines Magazine, Denver.
Mining and Contracting Review, Salt Lake City.
Mining and Geological Journal, Melbourne, Victoria, Australia.
Mining and Industrial News, San Francisco.
Mining and Metallurgy, New York.
Mining Congress Journal, Washington, D. C.
Mining Journal, London.
Mining Journal, Phoenix, Arizona.
Mining World, Seattle.
Nickel Steel Topics, New York City.
Oil and Gas Journal, Tulsa, Oklahoma.
Oil, Paint and Drug Reporter, New York.
Oil Weekly, Houston, Texas.
Pacific Purchaser, San Francisco.
Pacific Road Builder, San Francisco.
Pay Dirt, Phoenix, Arizona.
Petroleum World, Los Angeles.
Pit and Quarry, Chicago.
Rock Products, Chicago.
Rocks and Minerals, Peekskill, New York.
Scientific American, New York City.
Silicate, P's and Q's, Berkeley.
Standard Oil Bulletin, San Francisco.
Storage Battery Power, West Orange, N. J.

NEWSPAPERS

Current issues of the following papers are received and kept on file in the library:

Alaska Weekly, Seattle, Washington.
Amador Dispatch, Jackson, California.
Banner, Sonora, California.
Barstow Printer, Barstow, California.
Calaveras Californian, Angels Camp, California.
Calaveras Prospect, San Andreas, California.
Daily Commercial News, San Francisco, California.
Del Norte Triplicate, Crescent City, California.
Denver Mining Record, Denver, Colorado.
Feather River Bulletin, Quincy, California.
Inyo Independent, Independence, California.
Inyo Register, Bishop, California.
Las Vegas Age, Las Vegas, Nevada.
Mariposa Gazette, Mariposa, California.
Mining Press, Reno, Nevada.
Mohave Miner, Kingman, Arizona.
Mountain Messenger, Downieville, California.
Placer Herald, Auburn, California.
Placerville Times, Placerville, California.
Randsburg Times, Randsburg, California.
Terra Bella News, Terra Bella, California.
Tuolumne Independent, Sonora, California.
Tuolumne Prospector, Tuolumne, California.
Union, Grass Valley, Nevada City, California.
Union Democrat, Sonora, California.
Weekly Trinity Journal, Weaverville, California.
Yreka Journal, Yreka, California.

NEW BOOKS*

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Alderfer, E. B. and Michl, H. E., Economics of American Industry, 566 pp., New York, McGraw-Hill Book Co., 1942.

Amer. Soc. for Testing Materials, 1944 Book of Standards, 4 Vols., Parts I, II and 1945 Supplements to Parts I and II, Philadelphia, A.S.T.M.

A.S.T.M., Index to A.S.T.M. Standards, Dec. 1945, 224 pp., Philadelphia, Published by the Society.

A.S.T.M., Symposium on Plastics, 200 pp., Philadelphia, Published by the Society, 1944.

Andrews, A. I., Ceramic Tests and Calculations, 172 pp., New York, John Wiley & Sons, 1928.

Arthur, P. and Smith, O., Semimicro Qualitative Analysis, 2d Ed., 322 pp., McGraw-Hill Book Co., 1942.

Badger, W. L. and Baker, E. M., Inorganic Chemical Technology, 2d Ed., 237 pp., New York, McGraw-Hill Book Co., 1941.

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* List compiled by J. M. Little.

NEW BOOKS—Continued

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Branson, E. B. and **Tarr, W. A.,** 2d Ed., Introduction to Geology, 482 pp., New York, McGraw-Hill Book Co., 1941.

Buerger, M. J., X-Ray Crystallography, 531 pp., New York, John Wiley & Sons, 1942.

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de Donder, T. and **Van Rysselberghe, P.,** Thermodynamic Theory of Affinity, 142 pp., Stanford University Press, 1936.

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Fish, J. C. L., Engineering Economics, 2d Ed., 311 pp., New York, McGraw-Hill Book Co., 1923.

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Furnas, C. C., Roger's Industrial Chemistry, Vols. I and II, 6th Ed., New York, D. Van Nostrand Co., 1942.

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Groves, A. W., Silicate Analysis, 230 pp., New York, Nordeman Publishing Co., 1937.

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Gyngell, E. S., Applied Chemistry for Engineers, 328 pp., London, Edward Arnold & Co., 1940.

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Hauser, E. A., Colloidal Phenomena, 294 pp., New York, McGraw-Hill Book Co., 1939.

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SERVICES OF THE DIVISION OF MINES

The Division of Mines (formerly State Mining Bureau) is maintained for the purpose of assisting in all possible ways in the development of California's mineral resources.

As one means of offering tangible service to the mining public, the State Mineralogist for many years has issued an annual or a biennial report reviewing in detail the mines and mineral deposits of the various counties.

As a progressive step in advancing the interests of the mineral industry, and as permitting earlier distribution to the public, publication of the Annual Report of the State Mineralogist in the form of monthly chapters was begun in January 1922, and continued until March 1923. Owing to a lack of funds for printing this was changed to a quarterly publication, beginning in September 1923. For the same reason, beginning with the January 1924 issue, it became necessary to charge a subscription price. This covers approximately the cost of printing.

Pages are numbered consecutively throughout the year and an index to the complete report is included annually in the closing number.

Beginning with the 1930 issues, the activities and progress of the Geologic Branch are recorded also in these quarterly chapters. The important part that geology plays in the economic development of our mineral resources is further recognized in the change of title from *Mining in California* to CALIFORNIA JOURNAL OF MINES AND GEOLOGY, beginning with the January 1933 chapter.

While current activities of all descriptions are covered in these chapters, the practice of issuing from time to time technical reports on special subjects will be continued as well. A list of such reports now available is appended hereto, and the names of new bulletins will be added in the future as they are completed.

The chapters are subject to revision, correction and improvement. Constructive suggestions from the mining public will be gladly received, and are invited.

The one aim of the Division of Mines is to increase its usefulness and to stimulate the intelligent development of the wonderful, latent resources of the State of California.

TYPES OF REPORTS

In general the reports presented in these chapters are grouped into three classes:

1. Mines and mineral resources of a given county or area (describing kind, character, distribution and extent of development).

2. Specific economic and industrial mineral products (listing and describing the resources over the entire State of a given mineral substance, e.g., feldspar).

3. Geological reports on specific areas (recording results and conclusions with maps, derived from field studies; and tied in with economic possibilities and developments).

Reports of District Mining Engineers

In 1919-1920 the Mining Bureau was organized into four main geographical divisions, with the field work delegated to a mining engineer in each district, working out from field offices that were established in Redding, Auburn, San Francisco and Los Angeles, respectively. This move brought the office into closer personal contact with operators, and it has many advantages over former methods of conducting field work, including lower traveling-expense bills for the Bureau's engineers. In 1923 the Redding and Auburn field offices were consolidated and moved to Sacramento.

The Redding office was reestablished in 1928, and the boundaries of each district adjusted. The counties now included in each of the four divisions and the locations of the branch offices are shown on the frontispiece outline map of the State.

Reports of mining activities and development in each district, prepared by the District Engineer, will continue to appear under the proper field division heading.

Special Articles

Detailed technical reports on special subjects, the result of research work or extended field investigations, will continue to be issued as separate bulletins by the Division, as has been the custom in the past.

Shorter and less elaborate technical papers and articles by members of the staff and others are published in each number of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

These special articles cover a wide range of subjects both of historical and current interest; descriptions of new processes, or metallurgical and industrial plants, new mineral occurrences, and interesting geological formations, as well as articles intended to supply practical and timely information on the problems of the prospector and miner, such as the text of new laws and official regulations and notices affecting the mineral industry.

MAIL AND FILES

The Division of Mines maintains, in addition to its correspondence files and the library, a mine file which includes original reports on the various mines and mineral properties of all kinds in California.

During each quarterly period there are several thousand letters received and answered at the San Francisco office alone, covering almost every phase of prospecting, mining and developing mineral deposits, reduction problems, marketing of refined products and mining law. In addition to this, hundreds of oral questions are answered daily, both at the main office and the district offices, for the many inquirers who come in for personal interviews and to consult the files and library.

COMMERCIAL MINERAL NOTES

The producer and consumer of mineral products are mutually dependent upon each other for their prosperity, and one of the most direct aids rendered by this Division to the mining industry in the past has been that of bringing producers and consumers into direct touch with each other.

This work has been carried on largely by correspondence, supplemented by personal consultation. Lists of buyers of all the commercial minerals produced in California have been made available to producers

upon request, and likewise the owners of undeveloped deposits of various minerals, and producers of them, have been made known to those looking for raw mineral products.

When the publication of *Mining in California* was on a monthly basis, current inquiries from buyers and sellers were summarized and lists of mineral products or deposits 'wanted' or 'for sale' included in each issue.

It is important that inquiries of this nature reach the mining public as soon as possible and in order to avoid the delay incident to the present quarterly publication of CALIFORNIA JOURNAL OF MINES AND GEOLOGY, these lists are now issued monthly in the form of a mimeographed sheet under the title of *Commercial Mineral Notes,* and sent to those on the mailing list of CALIFORNIA JOURNAL OF MINES AND GEOLOGY.

EMPLOYMENT SERVICE

Following the establishment of the Mining Division branch offices in 1919, a free technical employment service was offered as a mutual aid to mine operators and technical men for the general benefit of the mineral industry.

Briefly summarized, men desiring positions are registered, the cards containing an outline of the applicant's qualifications, position wanted, salary desired, etc., and as notices of 'positions open' are received, the names and addresses of all applicants deemed qualified are sent to the prospective employer for direct negotiations.

Telephone and telegraphic communications are also given immediate attention.

Technical men, or those qualified for supervisory positions, and vacancies of like nature only, are registered, as no attempt will be made to supply mine and mill labor.

Registration cards for the use of both prospective employers and employees may be obtained upon request, and a cordial invitation is extended to the industry to make free use of the facilities afforded. Parties interested should communicate direct with our San Francisco office.

DETERMINATION OF MINERAL SAMPLES

Samples (limited to two at one time) of any mineral found in the State may be sent to the Division of Mines for identification, and the same will be classified free of charge. No samples will be determined if received from points outside the State. It must be understood that no assays, or quantitative determinations will be made. Samples should be in lump form if possible, and marked plainly with name of sender on outside of package, etc. No samples will be received unless delivery charges are prepaid. A letter should accompany sample, giving locality where mineral was found and the nature of the information desired.

PUBLICATIONS OF THE DIVISION OF MINES

During the past sixty-seven years, in carrying out the provisions of the organic act creating the former California State Mining Bureau, there have been published many reports, bulletins and maps which go to make up a library of detailed information on the mineral industry of the State, a large part of which could not be duplicated from any other source.

One feature that has added to the popularity of the publications is that many of them have been distributed without cost to the public, and even the more elaborate ones have been sold at a price which barely covers the cost of printing.

Owing to the fact that funds for the advancing of the work of this department have usually been limited, the reports and bulletins mentioned are printed in limited editions many of which are now entirely exhausted.

Copies of such publications are available for reference, however, in the offices of the Division of Mines, in the Ferry Building, San Francisco 11; State Building, Los Angeles 12; 631 J Street, Sacramento 14; Redding; and Division of Oil and Gas at Santa Maria, Santa Paula, Taft, Bakersfield, Coalinga. They may also be found in many public, private and technical libraries in California and other states and foreign countries.

A catalog of all publications from 1880 to 1917, giving a synopsis of their contents, is issued as Bulletin No. 77.

Publications in stock may be obtained postpaid by addressing the San Francisco, Los Angeles or Sacramento offices and enclosing the requisite amount.

Remittances of stamps in an amount not to exceed 26 cents, currency or coin will be accepted at sender's risk. Payment is preferred in the form of money orders.

Money orders should be made payable to the Division of Mines.

Write for latest revised price list.

NOTE.—The Division of Mines frequently receives requests for some of the early Reports and Bulletins now out of print, and it will be appreciated if parties having such publications and wishing to dispose of them will advise this office.

REPORTS

Asterisks (**) indicate the publication is out of print.	Price (including postage and sales tax)
**Report I of the State Mineralogist, 1880, 43 pp. Henry G. Hanks	----
**Report II of the State Mineralogist, 1882, 514 pp., 4 illustrations, 1 map. Henry G. Hanks	----
**Report III of the State Mineralogist, 1883, 111 pp., 21 illustrations. Henry G. Hanks	----
**Report IV of the State Mineralogist, 1884, 410 pp., 7 illustrations. Henry G. Hanks	----
**Report V of the State Mineralogist, 1885, 234 pp., 15 illustrations, 1 geological map. Henry G. Hanks	----
**Report VI of the State Mineralogist, Part 1, 1886, 145 pp., 3 illustrations, 1 map. Henry G. Hanks	----
Part II, 1887, 222 pp., 36 illustrations. William Irelan, Jr. Price $0.75, sales tax $0.02	$0.77
**Report VII of the State Mineralogist, 1887, 315 pp. William Irelan, Jr.	----
**Report VIII of the State Mineralogist, 1888, 948 pp., 122 illustrations. William Irelan, Jr.	----
Report IX of the State Mineralogist, 1889, 352 pp., 57 illustrations, 2 maps. William Irelan, Jr. Price $1.15, sales tax $0.03	1.18
**Report X of the State Mineralogist, 1890, 983 pp., 179 illustrations, 10 maps. William Irelan, Jr.	----
Report XI (First Biennial) of the State Mineralogist, for the two years ending September 15, 1892, 612 pp., 73 illustrations, 4 maps. William Irelan, Jr. Price $1.50, sales tax $0.04	1.54
**Report XII (Second Biennial) of the State Mineralogist, for the two years ending September 15, 1894, 541 pp., 101 illustrations, 5 maps. J. J. Crawford	----
**Report XIII (Third Biennial) of the State Mineralogist, for the two years ending September 15, 1896, 726 pp., 93 illustrations, 1 map. J. J. Crawford	----
Chapters of the State Mineralogist's Report XIV, Biennial Period, 1913-1914, Fletcher Hamilton:	
**Mines and Mineral Resources, Amador, Calaveras and Tuolumne Counties, 172 pp., paper	----
Mines and Mineral Resources, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma and Yolo Counties, 208 pp., paper Price $0.50, sales tax $0.01	.51
Mines and Mineral Resources, Del Norte, Humboldt and Mendocino Counties, 59 pp., paper Price $0.35, sales tax $0.01	.36
Mines and Mineral Resources, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin and Stanislaus Counties, 220 pp., paper Price $0.75, sales tax $0.02	.77
Mines and Mineral Resources of Imperial and San Diego Counties, 113 pp., paper Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, Shasta, Siskiyou and Trinity Counties, 180 pp., paper	----
**Report XIV of the State Mineralogist, for the Biennial Period 1913-1914, Fletcher Hamilton, 1915: A General Report on the Mines and Mineral Resources of Amador, Calaveras, Tuolumne, Colusa, Glenn, Lake, Marin, Napa, Solano, Sonoma, Yolo, Del Norte, Humboldt, Mendocino, Fresno, Kern, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, San Diego, Imperial, Shasta, Siskiyou and Trinity Counties, 974 pp., 275 illustrations, cloth	----
Chapters of the State Mineralogist's Report XV, Biennial Period, 1915-1916, Fletcher Hamilton:	
**Mines and Mineral Resources, Alpine, Inyo and Mono Counties, 176 pp., paper	----
Mines and Mineral Resources, Butte, Lassen, Modoc, Sutter and Tehama Counties, 91 pp., paper Price $0.50, sales tax $0.01	.51
**Mines and Mineral Resources, El Dorado, Placer, Sacramento and Yuba Counties, 198 pp., paper	----

REPORTS—Continued

Asterisks (**) indicate the publication is out of print. Price (including postage and sales tax)

**Mines and Mineral Resources, Monterey, San Benito, San Luis Obispo, Santa Barbara and Ventura Counties, 183 pp., paper	----
**Mines and Mineral Resources, Los Angeles, Orange and Riverside Counties, 136 pp., paper	----
**Mines and Mineral Resources, San Bernardino and Tulare Counties, 186 pp., paper	----
**Report XV of the State Mineralogist, for the Biennial Period 1915-1916, Fletcher Hamilton, 1917: A General Report on the Mines and Mineral Resources of Alpine, Inyo, Mono, Butte, Lassen, Modoc, Sutter, Tehama, Placer, Sacramento, Yuba, Los Angeles, Orange, Riverside, San Benito, San Luis Obispo, Santa Barbara, Ventura, San Bernardino and Tulare Counties, 990 pp., 413 illustrations, cloth	----
Chapters of the State Mineralogist's Report XVI, Biennial Period, 1917-1918, Fletcher Hamilton:	
**Mines and Mineral Resources of Nevada County, 270 pp., paper	----
Mines and Mineral Resources of Plumas County, 188 pp., paper Price $0.50, sales tax $0.01	$0.51
Mines and Mineral Resources of Sierra County, 144 pp., paper Price $0.75, sales tax $0.02	.77
Report XVII of the State Mineralogist, 1920, 'Mining in California during 1920,' Fletcher Hamilton; 562 pp., 71 illustrations, cloth Price $2.50, sales tax $0.06	2.56
Report XVIII of the State Mineralogist, 1922, 'Mining in California,' Fletcher Hamilton. Chapters published monthly beginning with January, 1922:	
**January, **February, **March, April, May, **June, July, August, September, October, November, December, 1922 Price each $0.30, sales tax $0.01	.31
Chapters of Report XIX of the State Mineralogist, 'Mining in California,' Fletcher Hamilton and Lloyd L. Root. January, February, March, September, 1923 Price each $0.30, sales tax $0.01	.31
Chapters of Report XX of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly. January, April, **July, October, 1924, per copy Price each $0.30, sales tax $0.01	.31
Chapters of Report XXI of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1925. Mines and Mineral Resources of Sacramento, Monterey and Orange Counties Price $0.30, sales tax $0.01	.31
**April, 1925. Mines and Mineral Resources of Calaveras, Merced, San Joaquin, Stanislaus and Ventura Counties	----
**July, 1925. Mines and Mineral Resources of Del Norte, Humboldt and San Diego Counties	----
**October, 1925. Mines and Mineral Resources of Siskiyou, San Luis Obispo and Santa Barbara Counties	----
Chapters of Report XXII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
**January, 1926. Mines and Mineral Resources of Trinity and Santa Cruz Counties	----
**April, 1926. Mines and Mineral Resources of Shasta, San Benito and Imperial Counties	----
July, 1926. Mines and Mineral Resources of Marin and Sonoma Counties Price $0.30, sales tax $0.01	.31
**October, 1926. Mines and Mineral Resources of El Dorado and Inyo Counties, also report on Minaret District, Madera County	----
Chapters of Report XXIII of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1927. Mines and Mineral Resources of Contra Costa County; Santa Catalina Island Price $0.30, sales tax $0.01	.31

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April, 1927. Mines and Mineral Resources of Amador and Solano Counties Price $0.30, sales tax $0.01	$0.31
**July, 1927. Mines and Mineral Resources of Placer and Los Angeles Counties	--
October, 1927. Mines and Mineral Resources of Mono County Price $0.30, sales tax $0.01	.31
Chapters of Report XXIV of the State Mineralogist, 'Mining in California,' Lloyd L. Root. Published quarterly:	
January, 1928. Mines and Mineral Resources of Tuolumne County Price $0.30, sales tax $0.01	.31
**April, 1928. Mines and Mineral Resources of Mariposa County	----
**July, 1928. Mines and Mineral Resources of Butte and Tehama Counties	----
October, 1928. Mines and Mineral Resources of Plumas and Madera Counties Price $0.30, sales tax $0.01	.31
Chapters of Report XXV of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
**January, 1929. Mines and Mineral Resources of Lassen, Modoc and Kern Counties; also on Special Placer Machines	----
**April, 1929. Mines and Mineral Resources of Sierra, Napa, San Francisco and San Mateo Counties	----
July, 1929. Mines and Mineral Resources of Colusa, Fresno and Lake Counties Price $0.30, sales tax $0.01	.31
October, 1929. Mines and Mineral Resources of Glenn, Alameda, Mendocino and Riverside Counties Price $0.30, sales tax $0.01	.31
Chapters of Report XXVI of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1930. Mines and Mineral Resources of Santa Clara County; also Barite in California Price $0.40, sales tax $0.01	.41
**April, 1930. Mines and Mineral Resources of Nevada County; also Mineral Paint Materials in California	----
**July, 1930. Mines and Mineral Resources of Yuba and San Bernardino Counties; also Commercial Grinding Plants in California	----
October, 1930. Mines and Mineral Resources of Butte, Kings and Tulare Counties; also Geology of Southwestern Mono County (Preliminary) Price $0.40, sales tax $0.01	.41
Chapters of Report XXVII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1931. Preliminary Report of Economic Geology of the Shasta Quadrangle. Beryllium and Beryl. The New Tariff and Nonmetallic Products. Crystalline talc. Decorative effects in Concrete Price $0.40, sales tax $0.01	.41
April, 1931. Stratigraphy of the Kreyenhagen Shale. Diatoms and Silicoflagellates of the Kreyenhagen Shale. Foraminifera of the Kreyenhagen Shale. Geology of Santa Cruz Island Price $0.40, sales tax $0.01	.41
**July, 1931. (Yuba, San Bernardino Counties.) Feldspar, Silica, Andalusite and Cyanite Deposits of California. Note on a Deposit of Andalusite in Mono County; its occurrence and chemical importance. Bill creating Trinity and Klamath River Fish and Game District and its effect upon mining	----
October, 1931. (Alpine County.) Geology of the San Jacinto Quadrangle south of San Gorgonio Pass, California. Notes on Mining Activities in Inyo and Mono Counties in July, 1931 Price $0.40, sales tax $0.01	.41
Chapters of Report XXVIII of the State Mineralogist, 'Mining in California,' Walter W. Bradley. Published quarterly:	
January, 1932, Economic Mineral Deposits of the San Jacinto Quadrangle. Geology and Physical Properties of Building Stone from Carmel Valley. Contributions to the Study of Sediments. Sediments of Monterey Bay. Sanbornite Price $0.40, sales tax $0.01	.41

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**April, 1932. Elementary Placer Mining Methods and Gold Saving Devices. The Pan, Rocker and Sluice Box. Prospecting for Vein Deposits. Bibliography of Placer Mining---- ----

**Abstract from April quarterly; Elementary Placer Mining Methods and Gold Saving Devices. Types of Deposits, Simple Equipment. Special Machines. Dry Washing. Black Sand Treatment. Marketing of Products. Placer Mining Areas. Laws. Prospecting for Quartz Veins. Bibliography (mimeographed)---- ----

**July-October, 1932. (Ventura County). Report accompanying Geologic Map of Northern Sierra Nevada. Fossil Plants in Auriferous Gravels of the Sierra Nevada. Glacial and Associated Stream Deposits of the Sierra Nevada. Jurassic and Cretaceous Divisions in the Knoxville Shasta Succession of California. Geology of a part of the Panamint Range. Economic Report of a Part of the Panamint Range. Acquiring Mining Claims Through Tax Title. The Biennial Report of State Mineralogist---- ----

Chapters of Report XXIX, 1933 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

**January-April, 1933. Gold Deposits of the Redding and Weaverville Quadrangles. Geologic Formations of the Redding-Weaverville District, Northern California. Geology of Portions of Del Norte and Siskiyou Counties. Applications of Geology to Civil Engineering. The Lakes of California. Discovery of Piedmontite in the Sierra Nevada. Tracing 'Buried River' Channel Deposits by Geomagnetic Methods. Geologic Map of Redding-Weaverville District, showing gold mines and prospects. Geologic map showing various mines and prospects of part of Del Norte and Siskiyou Counties---- ----

July-October, 1933. Gold Resources of Kern County. Limestone Deposits of the San Francisco Region. Limestone Weathering and Plant Associations of the San Francisco Region. Booming, Death Valley National Monument, California. Placer Mining Districts, Senate Bill 480. Navigable Waters, Assembly Bill 1543---- Price $1.00, sales tax $0.03 $1.03

Chapters of Report XXX, 1934 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

January, 1934. Resurrection of Early Surfaces in the Sierra Nevada. Geology and Mineral Resources of Northeastern Madera County. Geology and Mineral Deposits of Laurel and Convict Basins, Southwestern Mono County. Notes on Sampling as Applied to Gold Quartz Deposits----Price $0.60, sales tax $0.02 .62

April-July, 1934. Elementary Placer Mining in California and Notes on the Milling of Gold Ores----Price $1.00, sales tax $0.03 1.03

October, 1934. Current Mining Developments in Northern California. Current Mining Activity in Southern California. Geology and Mineral Resources of the Julian District, San Diego County. Geology and Mineral Resources of Elizabeth Lake Quadrangle, Dry Placers of Northern Mojave Desert. Biennial Report of State Mineralogist. Assessment Work Within Withdrawn Areas---- Price $0.60, sales tax $0.02 .62

Chapters of Report XXXI, 1935 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

January, 1935. Review of Gold Mining in East-Central California, 1934. Current Mining Activities in the San Francisco District with Special Reference to Gold. Geological Investigation of the Clays of Riverside and Orange Counties, Southern California. Information regarding Mining Loans by the Reconstruction Finance Corporation-- Price $0.60, sales tax $0.02 .62

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April, 1935. A Geologic Section Across the Southern Peninsular Range of California. New Technique Applicable to the Study of Placers. Grubstakes Permits—Price $0.60, sales tax $0.02 — $0.62

July, 1935. Mines and Mineral Resources of Siskiyou County (with map). Dams for Hydraulic Mining Debris. Leasing System as Applied to Metal Mining. Mine Financing in California. New Laws Make Radical Change in Mining Rights—Price $0.60, sales tax $0.02 — .62

October, 1935. Mines and Mineral Resources of San Luis Obispo County. Mineral Resources of Portions of Monterey and Kings Counties. Mining Activity at Soledad Mountain and Middle Buttes—Mojave District Kern County. Geology of a Portion of the Perris Block, Southern California. Mineral Resources of a Portion of the Perris Block, Riverside County—Price $0.60, sales tax $0.02 — .62

Chapters of Report XXXII, 1936 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

January, 1936. Gold Mines of Placer County, including Drag-line Dredges Geologic Report on Borax Lake, California—Price $0.60, sales tax $0.02 — .62

April, 1936. Geology, Mining and Processing of Diatomite at Lompoc, Santa Barbara County. Essentials in Developing and Financing a Prospect into a Mine. Gold-bearing Veins of Meadow Lake District, Nevada County. Semi-Precious Gem Stone Collection in Division Museum—Price $0.60, sales tax $0.02 — .62

July, 1936. Mines and Mineral Resources of Calaveras County. Mining in California by Power Shovel. Assessment Work on Mining Claims Within Withdrawn Areas. Joshua Tree National Monument. Cost of Producing Quicksilver at a California Mine in 1931-1932. The Age of Mineral Utilization—Price $0.60, sales tax $0.02 — .62

October, 1936. Mineral Resources of Lassen and Modoc Counties. Mechanics of Lone Mountain Landslides, San Francisco. Biennial Report of the State Mineralogist, Properties and Industrial applications of Opaline Silica—Price $0.60, sales tax $0.02 — .62

Chapters of Report XXXIII, 1937 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

January, 1937. Source Data of the Geologic Map of California, January, 1937. The Geology of Quicksilver Ore Deposits. Prospecting for Lode Gold—Price $0.60, sales tax $0.02 — .62

April, 1937. Mineral Resources of Plumas County (with Geologic Map). List of preferred mineral names. New Placer Mining Debris Law. Price $0.60, sales tax $0.02 — .62

July, 1937. Mineral Resources of Los Angeles County (with map showing principal Mines and Oil Fields). Geology and mineral deposits of the Western San Gabriel Mountains, Los Angeles County—Price $0.60, sales tax $0.02 — .62

October, 1937. Mineral Resources of the Resting Springs Region, Inyo County. Paleozoic Section in the Nopah and Resting Springs Mountains, Inyo County, California. Native Arsenic from Grass Valley, California—Price $0.60, sales tax $0.02 — .62

Chapters of Report XXXIV, 1938 (quarterly): titled 'California Journal of Mines and Geology,' containing the following:

**January, 1938. Mineral Development and Mining Activity in Southern California during the year 1937. Doing Something About Earthquakes. Gold and Petroleum in California. Gem Minerals of California, Lapidary Art— ----

April, 1938. Gold dredging in Shasta, Siskiyou and Trinity Counties; Geology of the Central Santa Monica Mountains; Marketing Mica Price $0.60, sales tax $0.02 — .62

July, 1938. El Dorado County, Mineral High-Lights of California; Strategic Minerals of California; Cyanide Treatment of Gossan at Mountain Copper Co.; Submarine Canyons off the California Coast. Price $0.60, sales tax $0.02 — .62

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	Price (including postage and sales tax)
October, 1938. **Inyo County**, Biennial Report of State Mineralogist, **Sulphur** Deposits of Inyo County, Geology of the **Darwin Silver-Lead Mining District** ---------------------- Price $0.60, sales tax $0.02	$0.62
Chapters of **Report XXXV**, 1939 (quarterly) titled "California Journal of Mines and Geology," containing the following:	
January, 1939. **San Diego County, Geology and Oil** Possibilities of Southwestern **San Diego** Co.; Prospect for **'Minor Metals' and Nonmetallic Minerals;** The **Right to Mine**------------ Price $0.60, sales tax $0.02	.62
April, 1939. **Shasta** County, Public's Interest in **Mine Taxation**--------- Price $0.60, sales tax $0.02	.62
July, 1939. **Tertiary** Formations of Northern **Sacramento Valley**, California; **Geology and Oil** Possibilities of **Caliente Range, Cuyama Valley and Carrizo Plain**, California; **Bibliography** of the Geology and Mineral Resources of California for the year 1937; The Giant **Goose Lake Meteorite** from Modoc County, California-------------- Price $0.60, sales tax $0.02	.62
October, 1939. **Quicksilver Resources of California; **Sulphate Minerals** of the Leviathan Sulphur Mine, Alpine County, California----------	----
Quicksilver Resources of California. Reprint--Price $0.50, sales tax $0.01	.51
Chapters of **Report XXXVI**, 1940 (quarterly) titled "California Journal of Mines and Geology," containing the following:	
January, 1940. Current Mining Activity in Southern California; Notes on **Beryl** with a **Qualitative Analysis for Beryllium; Strategic Minerals** Investigations Procedure followed by the U. S. Bureau of Mines------ Price $0.60, sales tax $0.02	.62
April, 1940. Mineral Resources of **Mono** County; General Geology and Ores of the **Blind Spring Hill** Mining District, Mono County, California; Short Report on the Geological Formations Encountered in Driving the **Mono Craters Tunnel; Methods and Costs** of Mining and Concentrating **Chromite** ---------------- Price $0.60, sales tax $0.02	.62
July, 1940. Economic Mineral Deposits of the **Newberry and Ord Mountains**, San Bernardino County; Geology of the Newberry and Ord Mountains, San Bernardino County, California; Notes on the Geology of a Portion of the **Calico Mountains**, San Bernardino County, California; Study of **Chrome Process** Aided by Martin Dennis Company Price $0.60, sales tax $0.02	.62
October, 1940. Mineral Resources of the **Kernville Quadrangle; Strategic Problems** of the Mineral Industry in California; Descriptive Geology of the Kernville Quadrangle, California; Biennial Report of the State Mineralogist; **Strategic Tax Exemption; Federal Loans for Strategic** Minerals ---------------------------- Price $0.60, sales tax $0.02	.62
Chapters of **Report XXXVII**, 1941 (quarterly) titled "California Journal of Mines and Geology," containing the following:	
January, 1941. Mineral Resources of **Trinity** County; **Strategic Minerals Procurement; Geologic** Investigation of the **Chromite** Deposits of California; United States Supreme Court Renders Far-reaching Decision on **Power Permits on "Navigable" Streams; Securities and Exchange Commission**---------------- Price $0.60, sales tax $0.02	.62
April, 1941. **Tungsten** Resources of California; Geological Progress of State Division of Mines; California **Earthquakes** of Mission Period, 1769-1838; **Marketing of Talc, Pyrophyllite and Ground Soap-Stone** Price $0.60, sales tax $0.02	.62
July, 1941. Nevada Co., report and map------ Price $0.60, sales tax $0.02	.62
October, 1941. **Humboldt County** report. **Tin** in California; California **Quicksilver** Program by the U. S. Geological Survey; Recent **Tungsten** Developments; **Manganese and Chrome Ore** Specifications and Prices; Does **Scheelite** always **Fluoresce? Bentonite**------------ Price $0.60, sales tax $0.02	.62

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Chapters of Report XXXVIII, 1942 (quarterly), titled "California Journal of Mines and Geology," containing the following:

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April, 1942. Imperial County report and map. Geology and Mineral Deposits of Cargo Muchacho Mountains—Price $0.60, sales tax $0.02 — .62

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**Map of Tuolumne County ---- ----
**Geographical Map of Inyo County. Scale 1 inch equals 4 miles---- ----
**Map of California accompanying Bulletin No. 89, showing generalized classification of land with regard to oil possibilities. Map only, without Bulletin ---- ----
**Geologic Map of California, 1916. Scale 1 inch equals 12 miles. Shows railroads, highways, post offices and other towns. Geological details lithographed in 23 colors. Mounted---- ----
**Unmounted ---- ----
Geologic Map of California, 1938. Scale 8 miles per inch. Lithographed in 80 distinguishing colors and patterns showing geolgic units. In 6 sections, each 32 in. x 42 in. Set of 6 sheets, unmounted. Sheets not sold separately----Price $4.00, sales tax $0.10 $4.10
**Topographic Map of Sierra Nevada Gold Belt, showing distribution of auriferous gravels, accompanying Bulletin No. 92. In 4 colors (also sold singly) ---- ----

Economic Series:
No. 1. Quicksilver
No. 2. Oil and Gas
No. 3. Chromite
No. 4. Tungsten
No. 5. Manganese
(See under separate listing below for prices)

Map of Ancient Channel System, Calaveras County----
Map of Ancient Channels Between San Andreas and Mokelumne Hill----
Price for set of 2 maps $0.25, sales tax $0.01 .26
Commercial Minerals of California, chart of---- Free
Geologic Map of Northern Sierra Nevada, showing Tertiary River Channels and Mother Lode Belt accompanying July-October, 1932, Chapter of Report XXVIII of the State Mineralogist. (Sold singly)----
Price $0.25, sales tax $0.01 .26
Map of Northern California, showing rivers and creeks which produced placer gold in 1932----Price $0.15, sales tax $0.01 .16
Redding and Weaverville Quadrangle Geologic Map and the Northwestern Part of the Red Bluff Quadrangle, showing location of gold mines. (Accompanying January-April, 1933, Chapter of Report XXXIX), sold separately----Price $0.15, sales tax $0.01 .16
Mother Lode, Geologic----Price .10
Mother Lode Maps showing Geology and Mining Claims in Amador, Calaveras, El Dorado, Mariposa, and Tuolumne Counties, accompanying Bulletin 108, 5 maps, sold separately, each----Price $0.15, sales tax $0.01 .16
**Geologic Map of Elizabeth Lake Quadrangle, Los Angeles and Kern Counties (accompanying October, 1934, Chapter of Report XXX)----
Mariposa Co. Map, accompanying report on Mines and Minerals of Mariposa Co. in January, 1935, Chapter of Report XXXI, sold separately
Price $0.15, sales tax $0.01 .16
Map of Western Portion of Siskiyou County Showing Location of Principal Gold Mines (accompanying July, 1935, Chapter of Report XXXI), sold separately----Price $0.15, sales tax $0.01 .16
Perris Block Map (accompanying Oct., 1935, Chapter of Report XXXI), sold separately ----Price .10
Plumas Co. Map, accompanying Report on Mines and Mineral Resources of Plumas Co. in April, 1937, Chapter of Report XXXIII, sold separately ----Price $0.15, sales tax $0.01 .16
Los Angeles County Map, accompanying report on mines and mineral resources of Los Angeles County, in July, 1937, Chapter of Report XXXIII, sold separately----Price $0.15, sales tax $0.01 .16
El Dorado Co. Map, accompanying report on Mines and Minerals of El Dorado Co. in July, 1938, Chapter of Report XXXIV, sold separately
Price $0.15, sales tax $0.01 .16

Other Maps—Continued

Asterisks (**) indicate the publication is out of print.	Price (including postage and sales tax)
Santa Monica Mts., Western, Geological Map of ---------- Price	$0.10
Inyo Co. Map, accompanying report on Mines and Minerals of Inyo Co., in October, 1938, Chapter of Report XXXIV, sold separately---------- Price $0.15, sales tax $0.01	.16
San Diego Co., Map, accompanying Report on Mines and Mineral Resources of San Diego Co. in January, 1939, Chapter of Report XXXV, sold separately ---------- Price $0.15, sales tax $0.01	.16
Shasta Co. Map, showing mines, accompanying Report on Mines and Mineral Resources of Shasta Co. in April, 1939, Chapter of Report XXXV, sold separately ---------- Price $0.15, sales tax $0.01	.16
Quicksilver deposits, sold in conjunction with October, 1939, Chapter of Report XXXV---------- Price $0.50, sales tax $0.02	.52
Mono County Map, accompanying report on mines and mineral resources of Mono County in April, 1940, Chapter of Report XXXVI, sold separately ---------- Price	.10
Kernville Quadrangle Geologic Map, accompanying report on mines and mineral resources of Kern Quadrangle in October, 1940, Chapter of Report XXXVI, sold separately---------- Price	.10
Trinity County, Showing Locations of Principal Mineral Deposits (accompanying January, 1941, Chapter of Report XXXVII)---------- Price $0.15, sales tax $0.01	.16
Chromite deposits (showing California geology uncolored)---------- Price $0.60, sales tax $0.02	.62
Grass Valley and Nevada City District claim map accompanying report on mines and mineral resources of Nevada Co. in July, 1941, Chapter of Report XXXVII, sold separately---------- Price	.10
Nevada City District Claim Map, accompanying report on mines and mineral resources of Nevada County in July, 1941, Chapter of Report XXXVII, sold separately---------- Price	.10
Nevada County Map, accompanying report on mines and mineral resources of Nevada County in July, 1941, Chapter of Report XXXVII, sold separately ---------- Price $0.15, sales tax $0.01	.16
Oil and Gas Fields (showing California geology uncolored), accompanying Bulletin 118, sold separately---------- Price $1.00, sales tax $0.03	1.03
Index map of **Economic Minerals and Geomorphic Provinces**----------	Free
Imperial Co. Map, accompanying report on mines and mineral resources of Imperial County in April, 1942, Chapter of Report XXXVIII, sold separately ---------- Price	.10
Tungsten Properties in California, accompanying July-October, 1942, Chapter of Report XXXVIII (showing California geology uncolored), sold separately ---------- Price $0.60, sales tax $0.02	.62
Santa Cruz Co. Map, accompanying report on mines and mineral resources of Santa Cruz County in January, 1943, Chapter of Report XXXIX, sold separately ---------- Price $0.15, sales tax $0.01	.16
San Benito Quadrangle Geologic Map, accompanying report on geology of area in April, 1943, Chapter of Report XXXIX, sold separately Price $0.40, sales tax $0.01	.41
San Bernardino County Map, accompanying report on mines and mineral resources of San Bernardino County in October, 1943, Chapter of Report XXXIX, sold separately---------- Price $0.15, sales tax $0.01	.16
Manganese Deposits (showing California geology uncolored), accompanying Bulletin 125, sold separately---------- Price $0.60, sales tax $0.02	.62
Jamesburg Quadrangle Geologic Map and Structure Section, accompanying report on geology of area in April, 1944, Chapter of Report XLI, sold separately---------- Price $0.40, sales tax $0.01	.41
Riverside County, accompanying report on mines and mineral resources of Riverside County in July 1945, Chapter of Report XLI, sold separately Price $0.15, sales tax $0.01	.16

OIL AND GAS FIELD MAPS

The following maps are on sale at the State Division of Oil and Gas, Ferry Building, San Francisco, and the various branch offices. The maps are revised as development work advances and ownerships change. Price includes postage and sales tax.

No.	*Price*
1—Sargent, Santa Clara County	$0.75
2—Santa Maria, including Cat Canyon—Los Alamos, Santa Barbara County	1.25
3—Santa Maria, including Casmalia and Lompoc, Santa Barbara County	1.25
4—Brea Olinda and East Coyote, Los Angeles, Orange Counties	1.25
6—Salt Lake—Beverly Hills, Los Angeles County	1.25
7—Sunset, including San Emidio, Kern County	1.25
8—South Midway, including Buena Vista Hills, Kern County	1.25
9—North Midway and McKittrick, Kern and San Luis Obispo Counties	1.25
10—South Belridge and McKittrick-Temblor oil fields, Kern County	1.25
11—Lost Hills and North Belridge, including Antelope Hills, Kern County	1.25
12—Devils Den, Kern County	1.00
13—Kern River and Kern Front fields, including portion of Poso Creek field, Kern County	1.00
14—Coalinga Jacalitos, and East Coalinga Extension, Fresno County	1.50
15—Elk Hills, Kern County	1.25
16—Ventura County, Ojai, Ventura County	1.75
17—Santa Paula-Ojai, including South Mountain, Ventura County	1.25
18—Sespe-Piru-Simi, including Bardsdale, Ventura County	1.50
18a—Newhall, Aliso Canyon, Newhall-Potrero, Del Valle and Oak Canyon, Los Angeles County	1.25
19—Arroyo Grande, San Luis Obispo County	1.00
20—Long Beach, Los Angeles County	1.75
21B—District 5, boundaries of areas including oil fields, Fresno, Kings and Kern Counties	1.00
21C—District 4, boundaries of areas including oil fields, Kern, Kings and Tulare Counties	1.25
22—District 3, boundaries of areas including oil fields, Santa Barbara County	.75
23—District 2, boundaries of areas including oil fields, Ventura County	1.00
24—District 1, boundaries of areas including oil fields, Los Angeles and Orange Counties	1.00
26—Huntington Beach, Orange County	1.50
27—Santa Fe Springs, Los Angeles County	1.25
28—Torrance, Los Angeles County	1.25
28a—Townlot area, Torrance field, Los Angeles County	.75
29—Dominguez, Los Angeles County	1.00
30—Rosecrans, Los Angeles County	1.25
31—Inglewood, Los Angeles County	1.25
32—Seal Beach, Los Angeles and Orange Counties	1.25
33—Rincon, Ventura County	----
34—Mt. Poso and Poso Creek, Kern County	1.00
35—Round Mountain, Kern County	1.00
36—Kettleman North Dome and Middle Dome, Fresno and Kings Counties	1.50
37—Montebello, Los Angeles County	1.00
38—Whittier, Los Angeles County	1.25
39—West Coyote Oil Field, Los Angeles and Orange Counties	1.25
40—Elwood, Goleta (abandoned), La Goleta (gas), Santa Barbara County	1.25
41—Potrero, Los Angeles County	1.00
42—Playa del Rey, Los Angeles County	1.50
43—Capitan, Santa Barbara County	1.00
44—Mesa, Santa Barbara County	1.50
46—Richfield, Orange County	1.25
48—Mountain View and Edison, Kern County	1.25
49—Fruitvale, Kern County	1.00

OIL AND GAS FIELD MAPS—Continued

No.	*Price*
50—Wilmington, Los Angeles County	$1.25
51—Santa Maria Valley, Santa Barbara County	1.00
52—El Segundo and Lawndale, Los Angeles County	1.50
53—Rio Bravo and Greeley, Kern County	1.00
54—Wasco oil field, Buttonwillow and Semitropic (gas), Kern County	1.25
55—Canal, Canfield Ranch, Coles Levee, Strand, Ten Section, Kern County	1.25
56—Paloma, Kern County	1.25
57—Rio Vista (gas), Sacramento, Solano, and Contra Costa Counties	1.00
58—Trico Gas, Kern, Kings and Tulare Counties	1.00
59—Raisin City, Helm and Riverside, including Wheatville area, Fresno County	1.25
60—West Newport and Newport, including Costa Mesa Area, Orange County	1.50
61—Wheeler Ridge and Tejon, Kern County	1.00

INDEX TO VOLUME XLII

Chapter 1, January *California Journal of Mines and Geology*, includes pp. 1-74.
Chapter 2, April *California Journal of Mines and Geology*, includes pp. 75-164.
Chapter 3, July *California Journal of Mines and Geology*, includes pp. 165-310.
Chapter 4, October *California Journal of Mines and Geology*, includes pp. 311-430.

A

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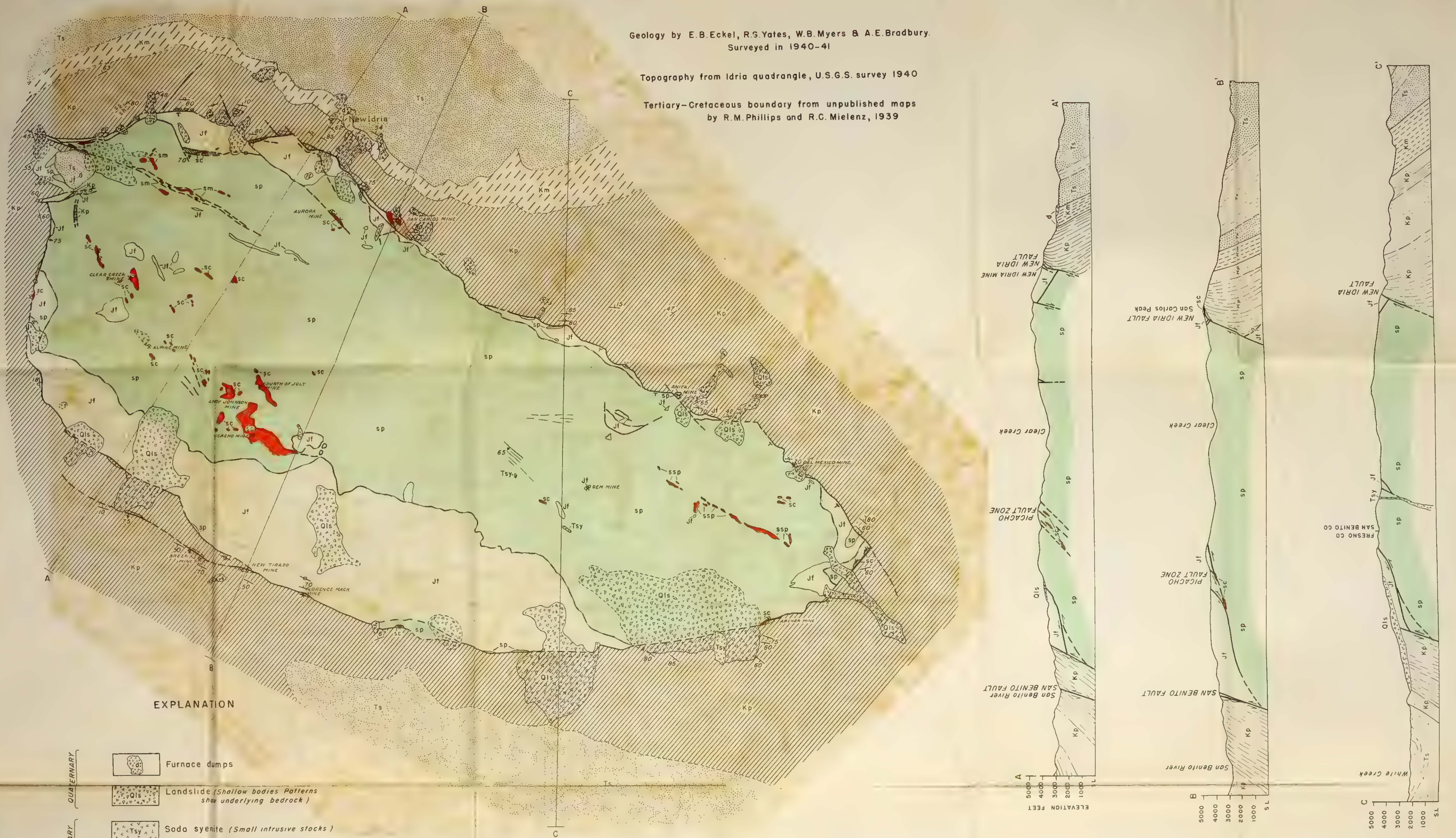
60107 7-46 2M



EXPLANATION

QUATERNARY

- Furnace dumps
- Landslide (Shallow bodies. Patterns show underlying bedrock.) — Qls

TERTIARY

- Soda syenite (Small intrusive stocks) — Tsy
- Eocene to Pliocene: Sediments, undivided. (Slightly consolidated shale, sandstone and conglomerate) — Ts

Cretaceous

- Moreno formation (Organic shale with several lenses of sandstone.) — Km
- Panoche formation (Gray shale and gray to brown, massive, concretionary sandstone) — Kp

Jurassic

- Serpentine (Altered ultrabasic, intrusive rock) — sp
- Franciscan group. (Massive, arkosic sandstone; minor shale, chert and greenstone.) — Jf

ROCK ALTERATIONS

- Silica-carbonate rock. (Altered serpentine, often contain minor cinnabar deposits.) — sc
- Silica-carbonate rock. (Altered serpentine, chief carbonate is magnesite.) — sm
- Slightly silicified serpentine — ssp
- Indurated shale or sandstone. (Contain principal cinnabar deposits of district)

CONTACTS

- Known position
- Approximate or inferred location
- Probably faulted

FAULTS

- Known location. T = upthrust side
- Approximate or inferred location
- Sheared and brecciated fault zone

- Strike and dip of beds
- Overturned beds
- Vertical beds
- Mine adit
- Mine or prospect

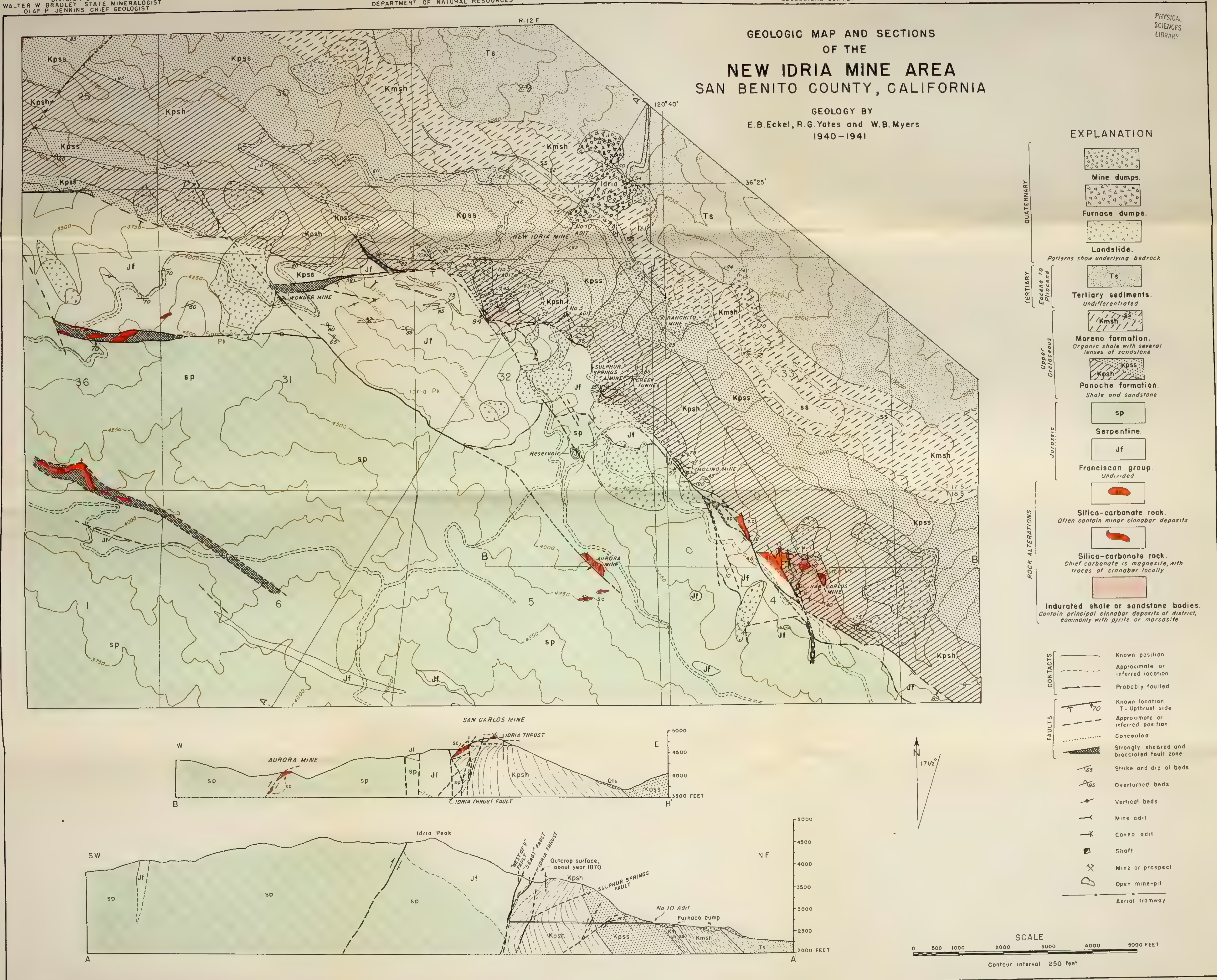
GEOLOGIC MAP AND SECTIONS OF THE NEW IDRIA DISTRICT

SAN BENITO AND FRESNO COUNTIES CALIFORNIA

SCALE

0 1 2 3 4 5 Miles

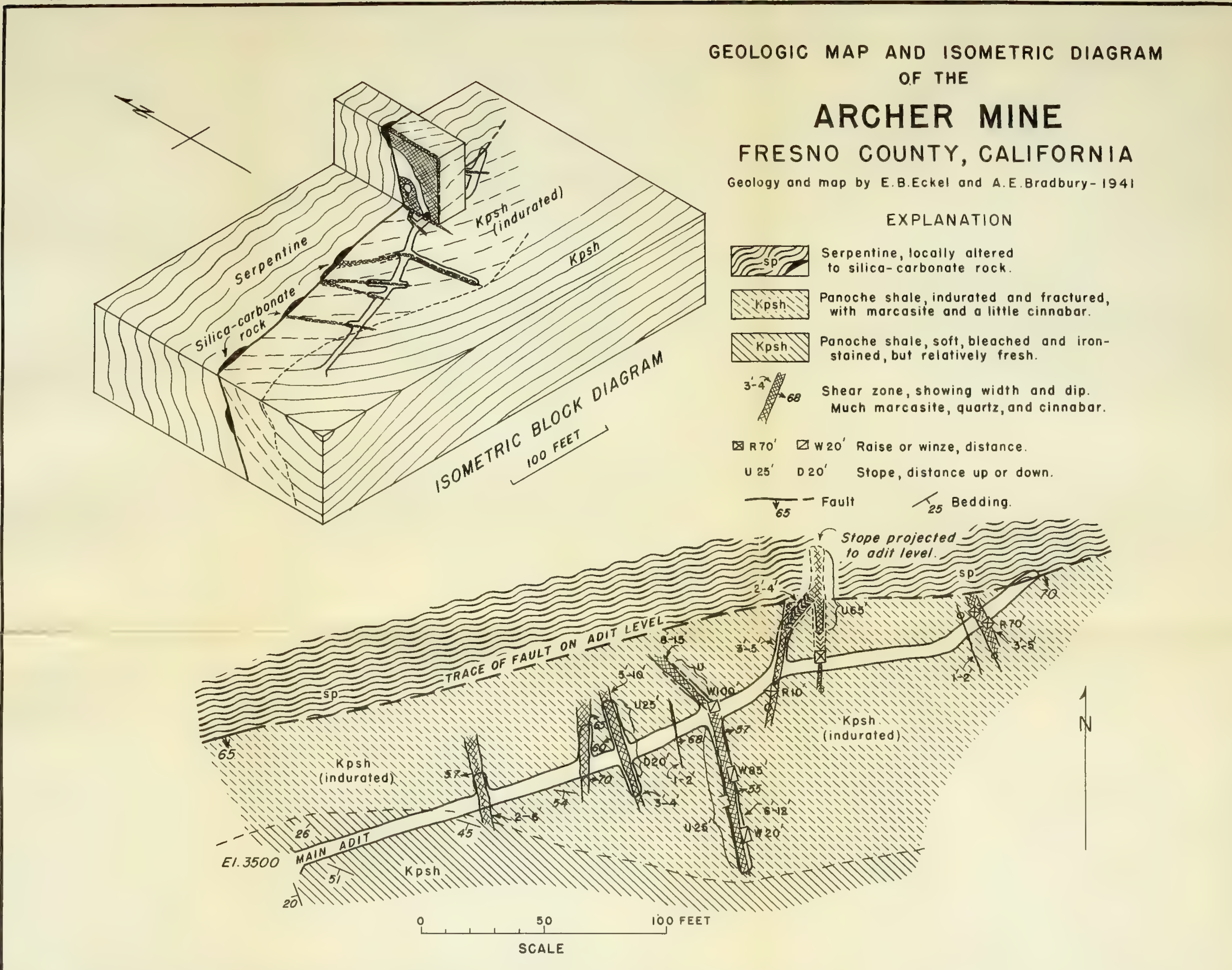
Contour interval 50 feet.

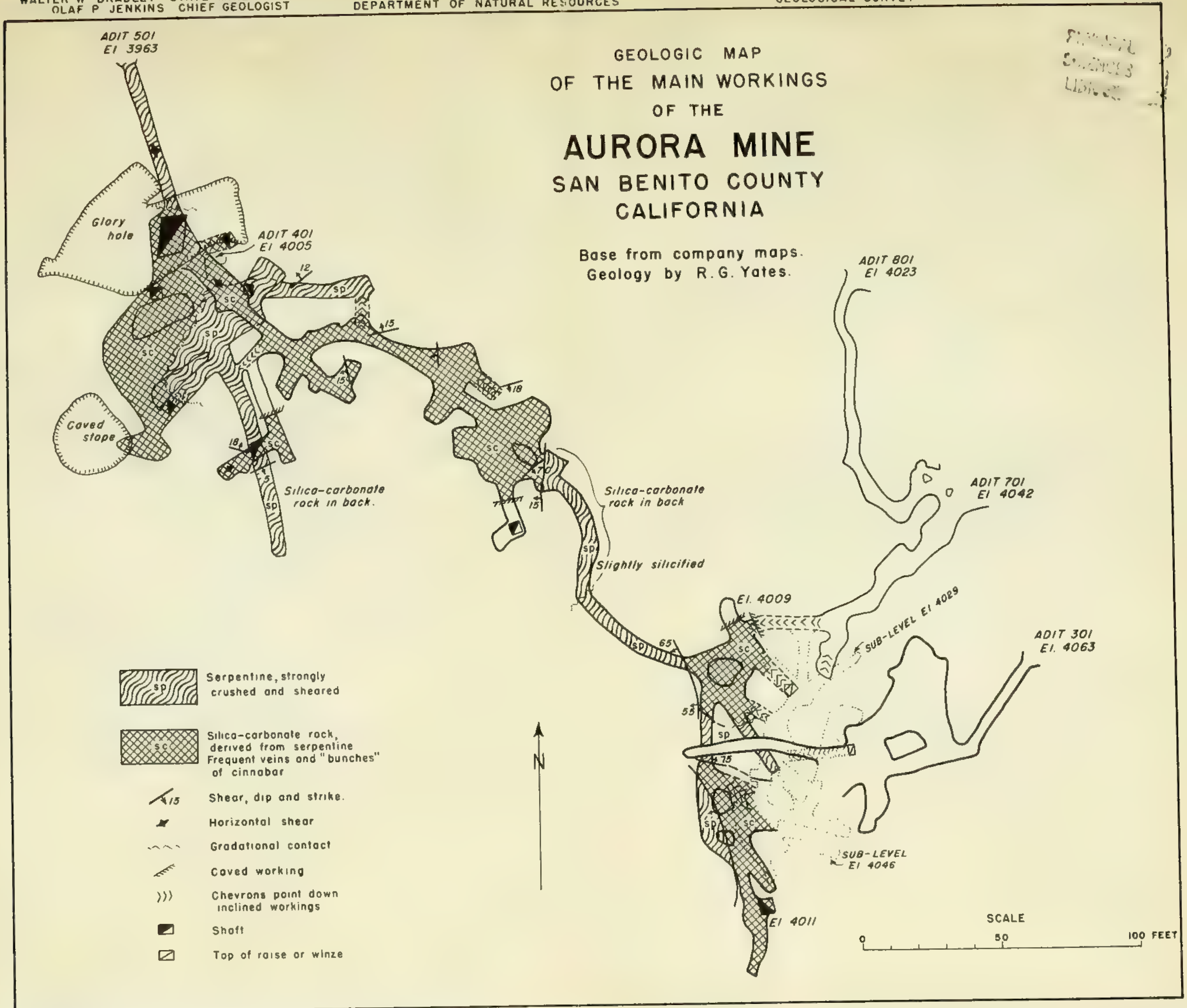

GEOLOGIC MAP AND SECTIONS
OF THE
NEW IDRIA MINE AREA
SAN BENITO COUNTY, CALIFORNIA
GEOLOGY BY
E.B. Eckel, R.G. Yates and W.B. Myers
1940-1941
PHYSICAL SCIENCES LIBRARY
EXPLANATION
QUATERNARY
Mine dumps.
Furnace dumps.
Landslide.
Patterns show underlying bedrock
TERTIARY
Eocene to Pliocene
Ts
Tertiary sediments.
Undifferentiated
Upper Cretaceous
Kmsh
ss
Moreno formation.
Organic shale with several lenses of sandstone
Kpss
Kpsh
Panoche formation.
Shale and sandstone
Jurassic
sp
Serpentine.
Jf
Franciscan group.
Undivided
ROCK ALTERATIONS
Silica-carbonate rock.
Often contain minor cinnabar deposits
Silica-carbonate rock.
Chief carbonate is magnesite, with traces of cinnabar locally
Indurated shale or sandstone bodies.
Contain principal cinnabar deposits of district, commonly with pyrite or marcasite
CONTACTS
Known position
Approximate or inferred location
Probably faulted
FAULTS
Known location
T = Upthrust side
Approximate or inferred position.
Concealed
Strongly sheared and brecciated fault zone
Strike and dip of beds
Overturned beds
Vertical beds
Mine adit
Caved adit
Shaft
Mine or prospect
Open mine-pit
Aerial tramway
SCALE
0 500 1000 2000 3000 4000 5000 FEET
Contour interval 250 feet
N
17½°
R.12 E
120°40'
36°25'
T.17 S.
T.18 S.
NEW IDRIA MINE
No 10 ADIT
No 5 ADITS
No 3 ADIT
Idria
WONDER MINE
RANCHITO MINE
SULPHUR SPRINGS MINE
GREEN TUNNEL
MOLINO MINE
AURORA MINE
SAN CARLOS MINE
Reservoir
Idria Pk
San Carlos Pk
SAN CARLOS MINE
IDRIA THRUST
AURORA MINE
IDRIA THRUST FAULT
W
E
B
B'
5000
4500
4000
3500 FEET
Idria Peak
"WEST OF 9" FAULT
"5 EAST" FAULT
IDRIA THRUST
Outcrop surface, about year 1870
SULPHUR SPRINGS FAULT
No 10 Adit
Furnace dump
SW
NE
A
A'
5000
4500
4000
3500
3000
2500
2000 FEET

GEOLOGIC MAP AND ISOMETRIC DIAGRAM OF THE ARCHER MINE

FRESNO COUNTY, CALIFORNIA

Geology and map by E.B.Eckel and A.E.Bradbury - 1941



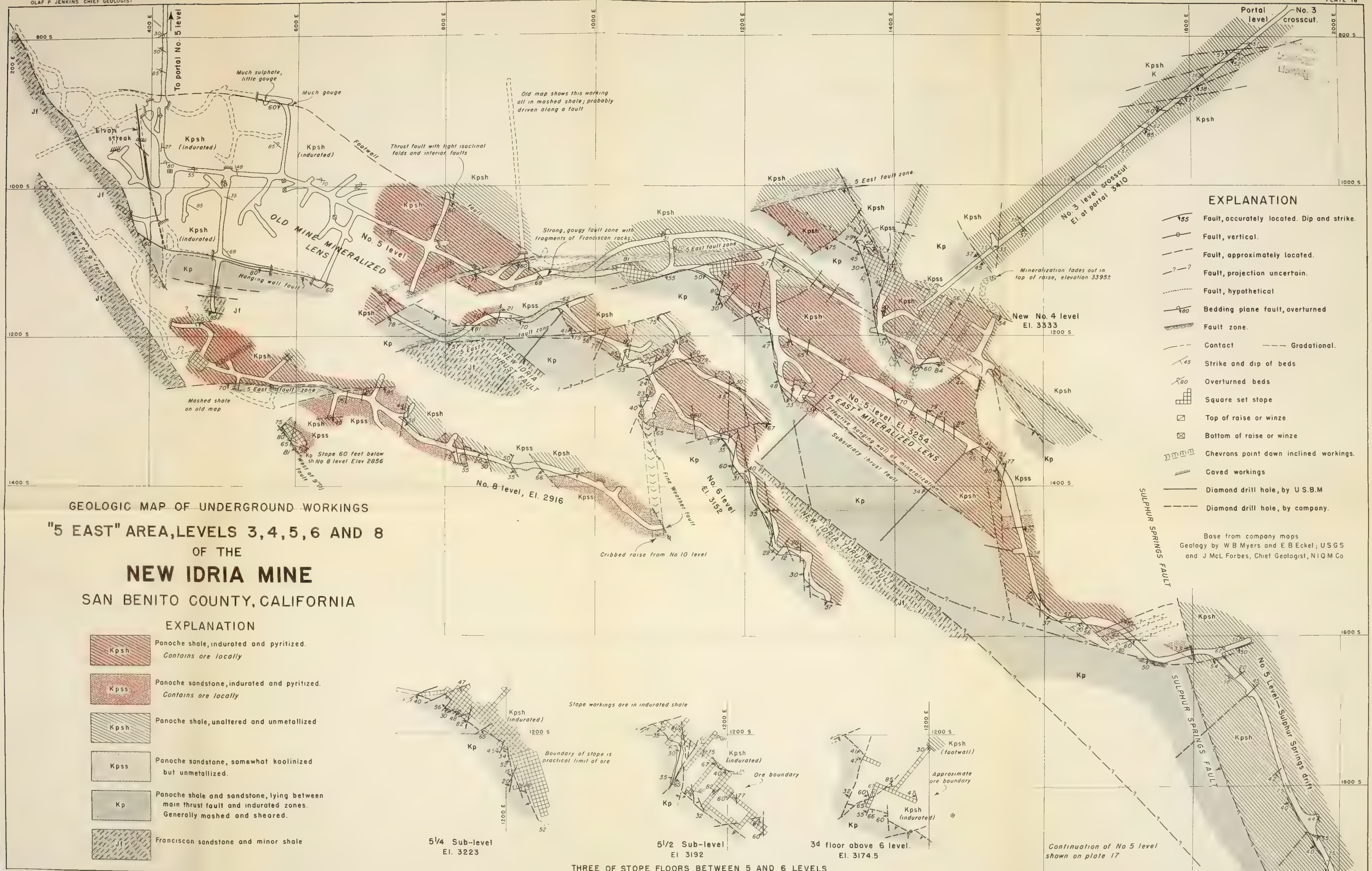

GEOLOGIC MAP
OF THE MAIN WORKINGS
OF THE
AURORA MINE
SAN BENITO COUNTY
CALIFORNIA
Base from company maps.
Geology by R. G. Yates.
ADIT 501
El 3963
Glory hole
ADIT 401
El 4005
Caved stope
Silica-carbonate rock in back.
Silica-carbonate rock in back
Slightly silicified
ADIT 801
El 4023
ADIT 701
El 4042
El. 4009
SUB-LEVEL El 4029
ADIT 301
El. 4063
SUB-LEVEL
El 4046
El 4011
Serpentine, strongly crushed and sheared
Silica-carbonate rock, derived from serpentine Frequent veins and "bunches" of cinnabar
Shear, dip and strike.
Horizontal shear
Gradational contact
Caved working
Chevrons point down inclined workings
Shaft
Top of raise or winze
N
SCALE
0
50
100 FEET

DIVISION OF MINES
WALTER W. BRADLEY STATE MINERALOGIST
OLAF P. JENKINS CHIEF GEOLOGIST

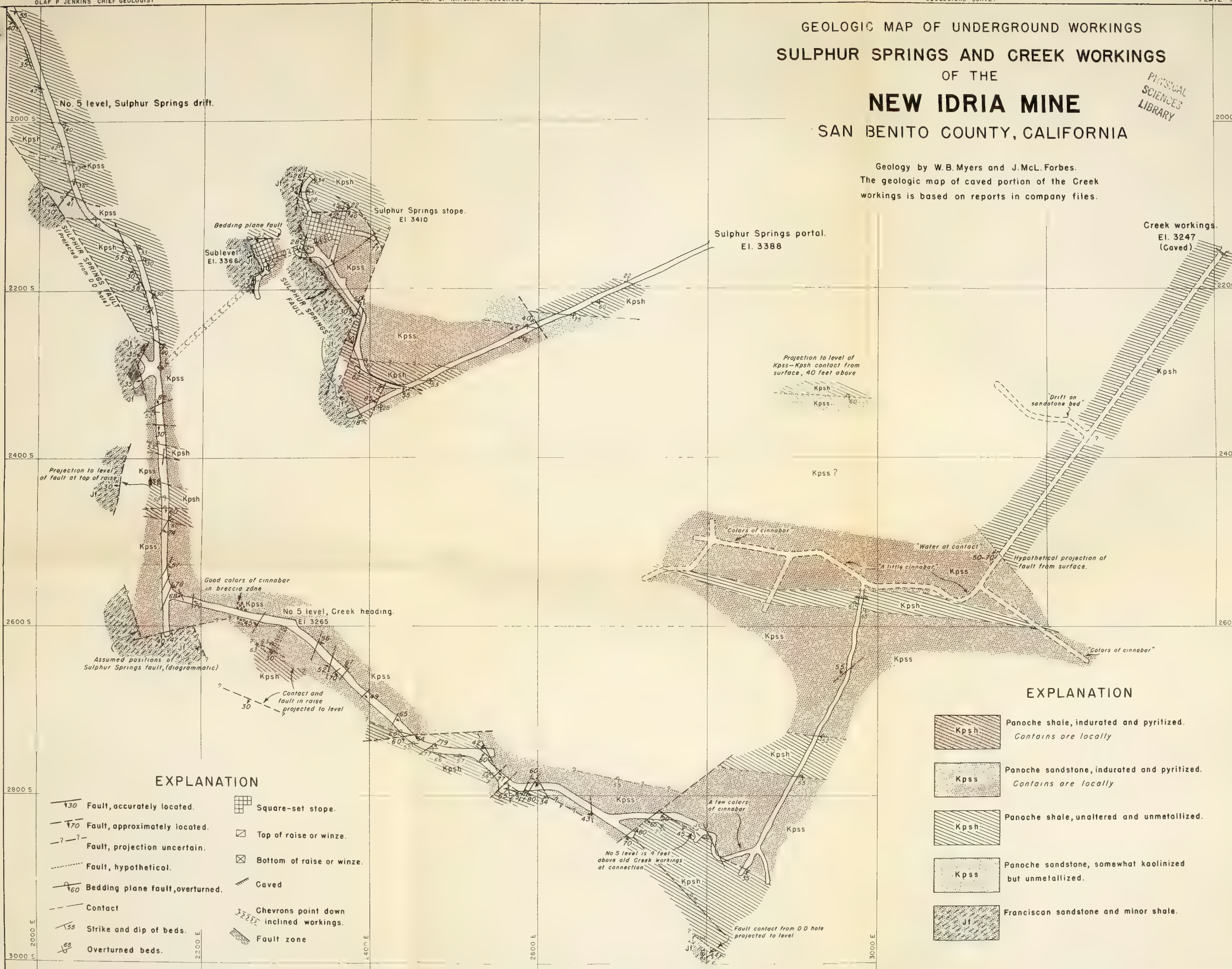
STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

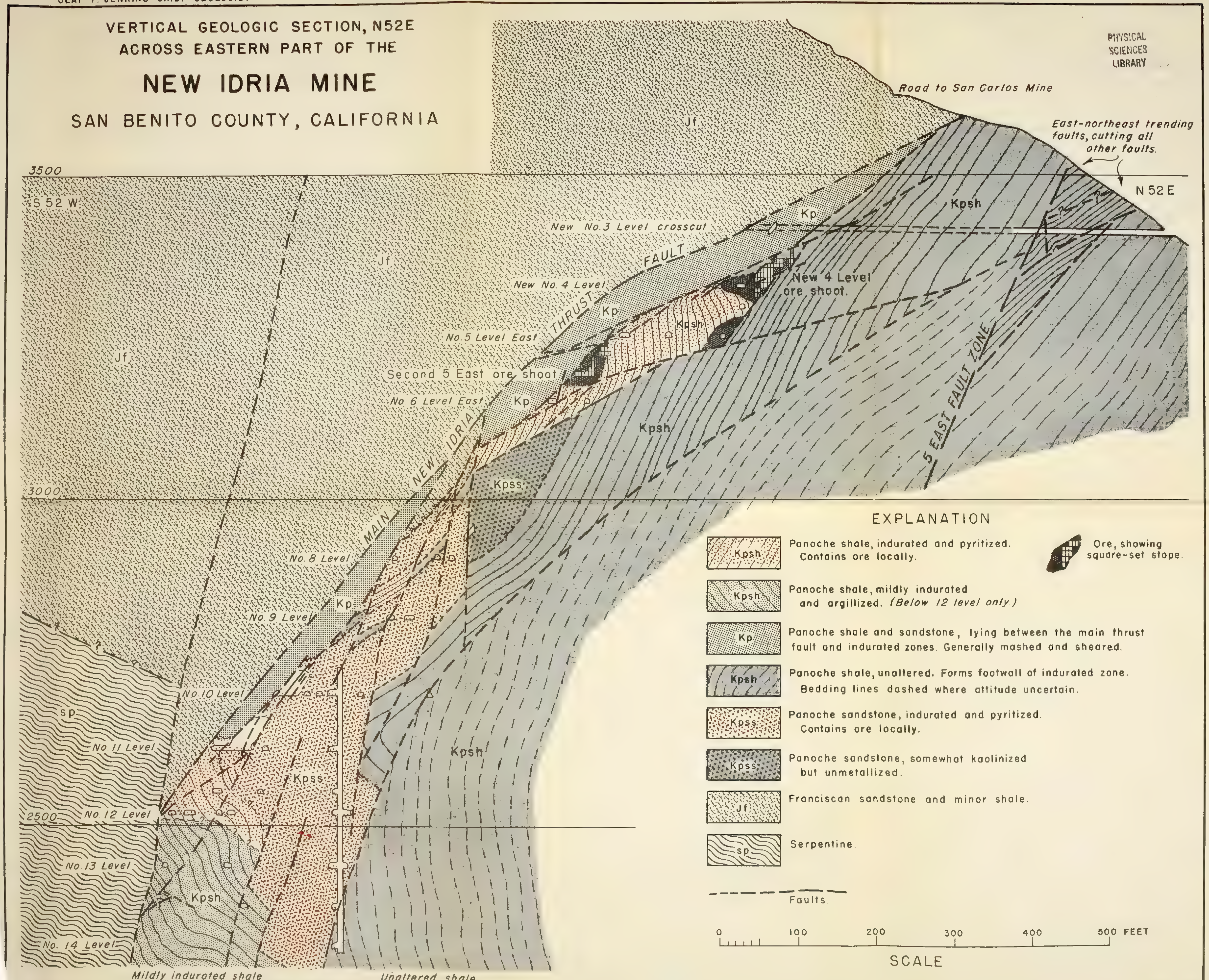
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 16



ACCOMPANYING STATE MINERALOGIST'S REPORT XLII APRIL 1946


GEOLOGIC MAP OF UNDERGROUND WORKINGS
SULPHUR SPRINGS AND CREEK WORKINGS
OF THE
NEW IDRIA MINE
SAN BENITO COUNTY, CALIFORNIA
Geology by W. B. Myers and J. McL. Forbes.
The geologic map of caved portion of the Creek workings is based on reports in company files.
No. 5 level, Sulphur Springs drift.
Sulphur Springs stope. El. 3410
Bedding plane fault
Sublevel El. 3366
Sulphur Springs portal. El. 3388
Creek workings. El. 3247 (Caved)
SULPHUR SPRINGS FAULT (Projected from D.D. hole)
SULPHUR SPRINGS FAULT
Projection to level of Kpss–Kpsh contact from surface, 40 feet above
"Drift on sandstone bed"
Projection to level of fault at top of raise
Kpss ?
"Colors of cinnabar"
"Water at contact"
"A little cinnabar"
Hypothetical projection of fault from surface.
Good colors of cinnabar in breccia zone
No. 5 level, Creek heading. El. 3265
Assumed positions of Sulphur Springs fault, (diagrammatic)
Contact and fault in raise projected to level
"Colors of cinnabar"
A few colors of cinnabar
No. 5 level is 4 feet above old Creek workings at connection.
Fault contact from D.D. hole projected to level
2000 S
2200 S
2400 S
2600 S
2800 S
3000 S
2000 E
2200 E
2400 E
2600 E
3000 E
EXPLANATION
Fault, accurately located.
Fault, approximately located.
Fault, projection uncertain.
Fault, hypothetical.
Bedding plane fault, overturned.
Contact
Strike and dip of beds.
Overturned beds.
Square-set stope.
Top of raise or winze.
Bottom of raise or winze.
Caved
Chevrons point down inclined workings.
Fault zone
EXPLANATION
Kpsh Panoche shale, indurated and pyritized. Contains ore locally
Kpss Panoche sandstone, indurated and pyritized. Contains ore locally
Kpsh Panoche shale, unaltered and unmetallized.
Kpss Panoche sandstone, somewhat kaolinized but unmetallized.
Jf Franciscan sandstone and minor shale.

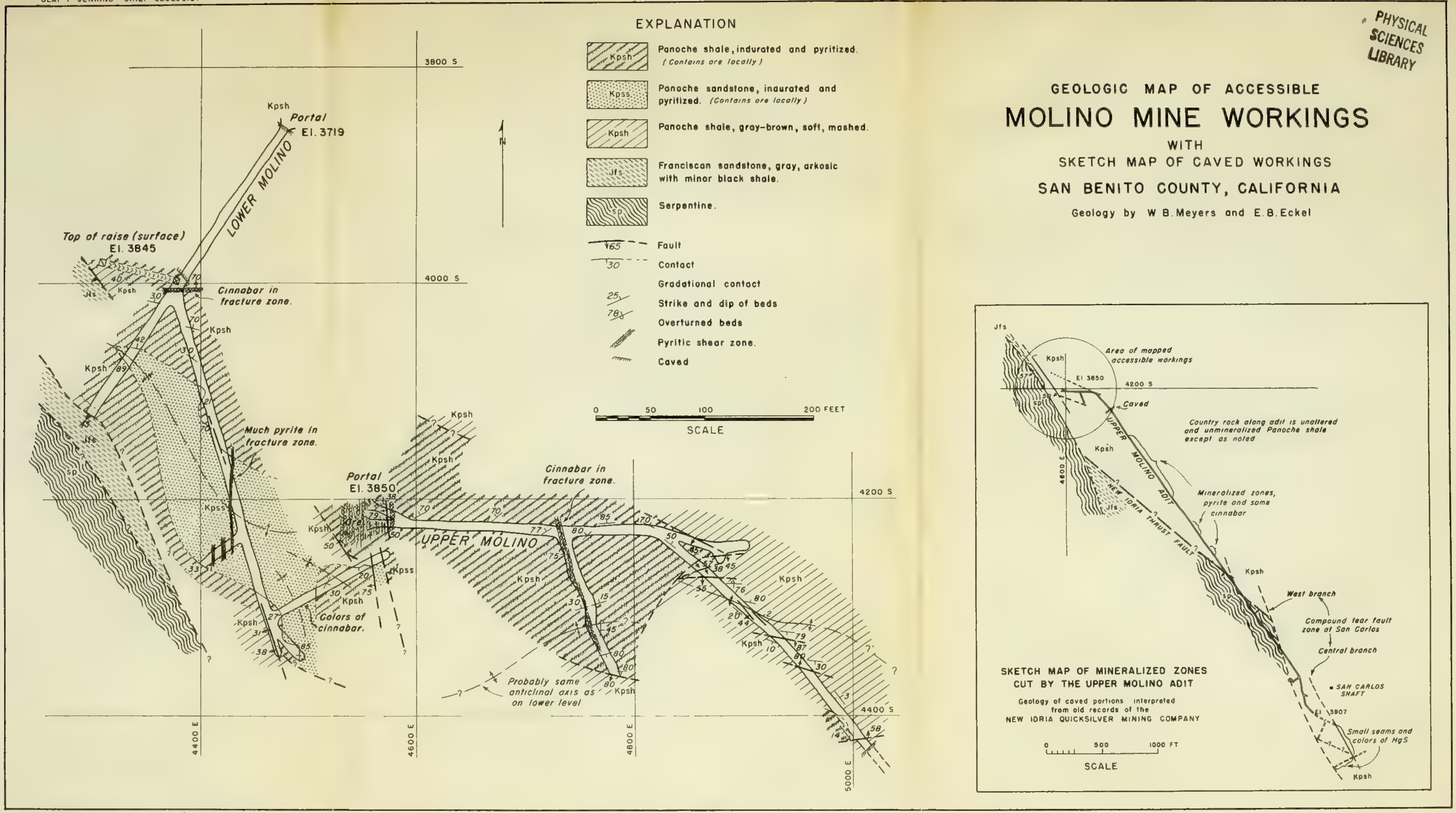

VERTICAL GEOLOGIC SECTION, N52E
ACROSS EASTERN PART OF THE
NEW IDRIA MINE
SAN BENITO COUNTY, CALIFORNIA
PHYSICAL SCIENCES LIBRARY
Road to San Carlos Mine
East-northeast trending faults, cutting all other faults.
3500
3000
2500
S 52 W
N 52 E
Jf
Kp
Kpsh
Kpss
sp
New No.3 Level crosscut
MAIN NEW IDRIA THRUST FAULT
New No. 4 Level
New 4 Level ore shoot.
No.5 Level East
Second 5 East ore shoot
No. 6 Level East
5 EAST FAULT ZONE
No. 8 Level
No. 9 Level
No. 10 Level
No. 11 Level
No. 12 Level
No. 13 Level
No. 14 Level
Mildly indurated shale
Unaltered shale
EXPLANATION
Kpsh Panoche shale, indurated and pyritized. Contains ore locally.
Ore, showing square-set stope.
Kpsh Panoche shale, mildly indurated and argillized. (Below 12 level only.)
Kp Panoche shale and sandstone, lying between the main thrust fault and indurated zones. Generally mashed and sheared.
Kpsh Panoche shale, unaltered. Forms footwall of indurated zone. Bedding lines dashed where attitude uncertain.
Kpss Panoche sandstone, indurated and pyritized. Contains ore locally.
Kpss Panoche sandstone, somewhat kaolinized but unmetallized.
Jf Franciscan sandstone and minor shale.
sp Serpentine.
Faults.
0 100 200 300 400 500 FEET
SCALE

DIVISION OF MINES
WALTER W BRADLEY STATE MINERALOGIST
OLAF P JENKINS CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 19



ACCOMPANYING STATE MINERALOGIST'S REPORT XLII APRIL 1946

MAP OF UNDERGROUND WORKINGS
SAN CARLOS MINE
SAN BENITO COUNTY, CALIFORNIA

GEOLOGIC AND TOPOGRAPHIC MAP
OF THE
SULPHUR BANK MINE AREA
LAKE COUNTY, CALIFORNIA

GEOLOGY BY Don L Everhart
AUGUST 1943

Contour interval 25 feet

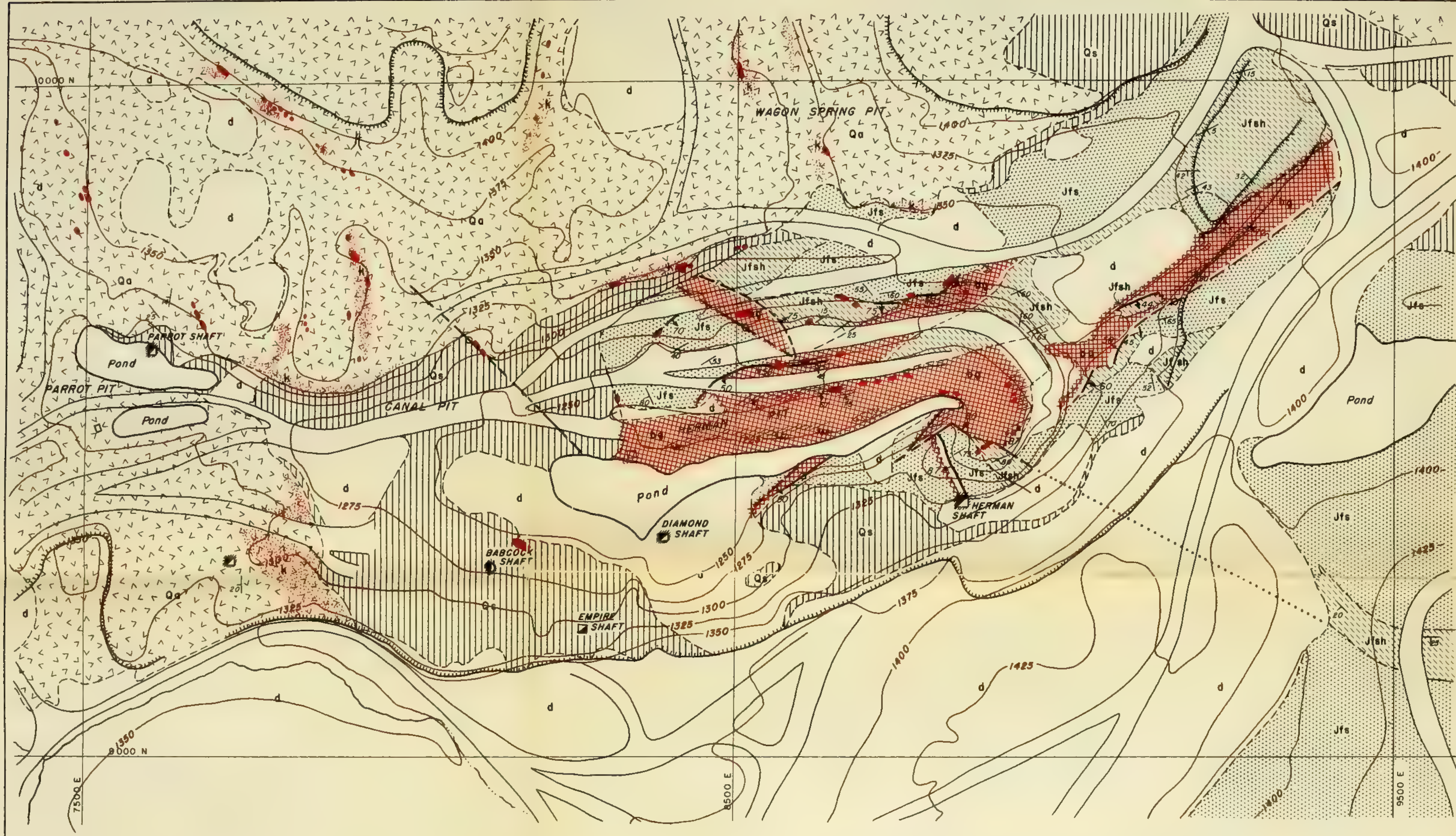
SCALE

DIVISION OF MINES
WALTER W BRADLEY STATE MINERALOGIST
OLAF P JENKINS CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE 22.



QUATERNARY

d	Obscured by waste dumps, road surfacing and water.
	Commercial concentrations of cinnabar.
Qa, k	Augite andesite, k, highly kaolinized.
Qs	Sediments, largely kaolinized sandstone breccia and sandstone.

Franciscan

bg	Fault gouge and breccia.
Jfsh	Contorted shale.
Jfs	Contorted sandstone.

Exposed contact.
Inferred contact
Bedding or sheeting.
Joint.
Known fault.
Projected fault.
Inferred fault.
Doubtful fault.
Shear zone.
Abandoned adit
Shaft. Caved.
Pit boundary.

GEOLOGIC AND TOPOGRAPHIC MAP OF THE SULPHUR BANK MINE PIT AREA

ENLARGED PORTION, 9000 N TO 10000 N AND 7500 E TO 9500 E, OF PLATE 21

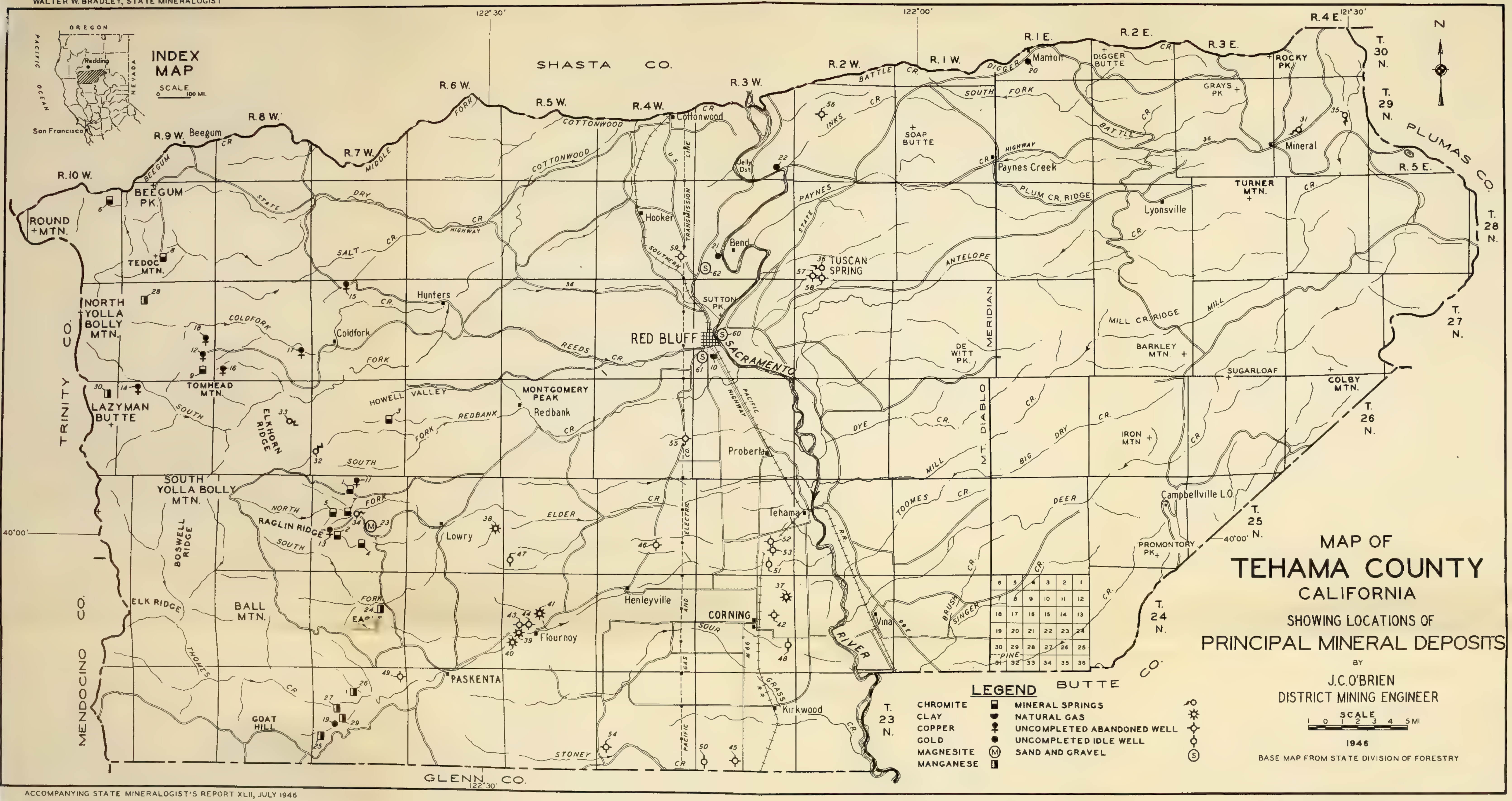
Contour interval 25 feet.

0 100 500 1000 FEET
SCALE

DIVISION OF MINES
WALTER W. BRADLEY, STATE MINERALOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

PLATE 28



ACCOMPANYING STATE MINERALOGIST'S REPORT XLII, JULY 1946

LIST OF PRINCIPAL MINERAL DEPOSITS TEHAMA COUNTY, CALIFORNIA

Map No.

CHROMITE

1. Basler Mining & Development Co., secs. 4, 8, T. 25 N., R. 7 W.
2. Big Bear chrome mine, NE¼ sec. 20, T. 25 N., R. 7 W.
3. Hensley & Hazelwood, secs. 13, 14, T. 26 N., R. 7 W.
4. Kleinsorge, sec. 27, T. 25 N., R. 7 W.
5. McLaughlin & Applegarth (Grau mine), sec. 17, T. 25 N., R. 7 W.
6. Moore & Robinson (Beegum mine), secs. 11, 12, T. 28 N., R. 10 W.
7. Noble Electric, sec. 16, T. 25 N., R. 7 W.
8. Tedoc chrome mine, sec. 28, T. 28 N., R. 9 W.
9. Toms Head mine, sec. 36, T. 27 N., R. 9 W.

CLAY

10. O'Connor Bros., sec. 29, T. 27 N., R. 3 W.

COPPER

11. Basler (White Bluff group), sec. 4, T. 25 N., R. 7 W.
12. California & Massachusetts, sec. 25, T. 27 N., R. 9 W.
13. Elder Creek group, sec. 20, T. 25 N., R. 7 W.
14. Halley, sec. 5, T. 26 N., R. 9 W.
15. Kestner & Thompson, sec. 4, T. 27 N., R. 7 W.
16. Tom Head, sec. 31, T. 27 N., R. 8 W.
17. Uncle Sam, sec. 25, T. 27 N., R. 8 W.
18. Verde, sec. 24, T. 27 N., R. 9 W.

GOLD

19. Bower's Creek mine, sec. 20, T. 23 N., R. 7 W.
20. Joe Arnol prospect, sec. 28, T. 30 N., R. 1 E.
21. Midland Dredging Co., sec. 29, T. 28 N., R. 3 W.
22. Tehama Dredging Co., secs. 35, 36, T. 29 N., R. 3 W.

MAGNESITE

23. El Soledad, Big Slide, and Big Springs group, sec. 22, T. 25 N., R. 7 W.

MANGANESE

24. Cavaleri, sec. 14, T. 24 N., R. 7 W.
25. Elva, sec. 30, T. 23 N., R. 7 W.
26. Lockwood, sec. 9, T. 23 N., R. 7 W.
27. Logan, sec. 17, T. 23 N., R. 7 W.
28. Manganese King, sec. 8, T. 27 N., R. 9 W.
29. Manganese Peak, sec. 20, T. 23 N., R. 7 W.
30. Tehama, secs. 1, 2, 11, 12, T. 26 N., R. 10 W.

MINERAL SPRINGS

31. Battle Creek Meadows, White Sulphur Springs, sec. 20, T. 29 N., R. 4 E.
32. Colyear Springs, sec. 30, T. 26 N., R. 7 W.
33. Hensley Springs, sec. 14, T. 26 N., R. 8 W.
34. Hickman Mineral Salt Springs, Tehama Mineral Spring, sec. 16, T. 25 N., R. 7 W.
35. Morgan Hot Spring, sec. 14, T. 29 N., R. 4 E.
36. Tuscan Springs, NE¼ sec. 32, T. 28 N., R. 2 W.

NATURAL GAS

37. Superior Oil Co., "Saldubehere" 1, sec. 12, T. 24 N., R. 3 W.

Shallow wells reported producing useable amounts of gas

38. Sec. 24, T. 25 N., R. 6 W.
39. Sec. 20, T. 24 N., R. 5 W.
40. Sec. 30, T. 24 N., R. 5 W.
41. Sec. 16, T. 24 N., R. 5 W.

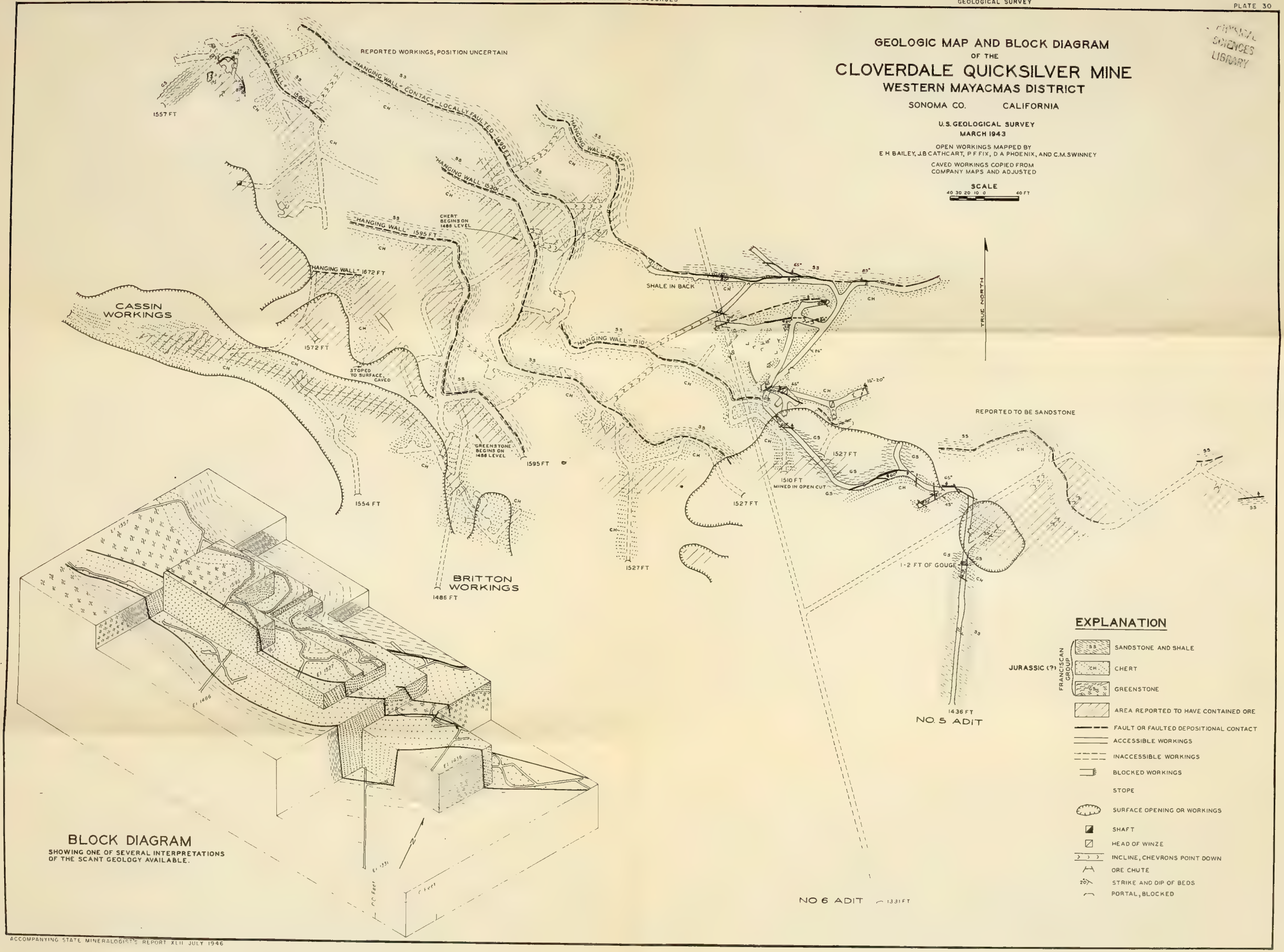
Other Wells

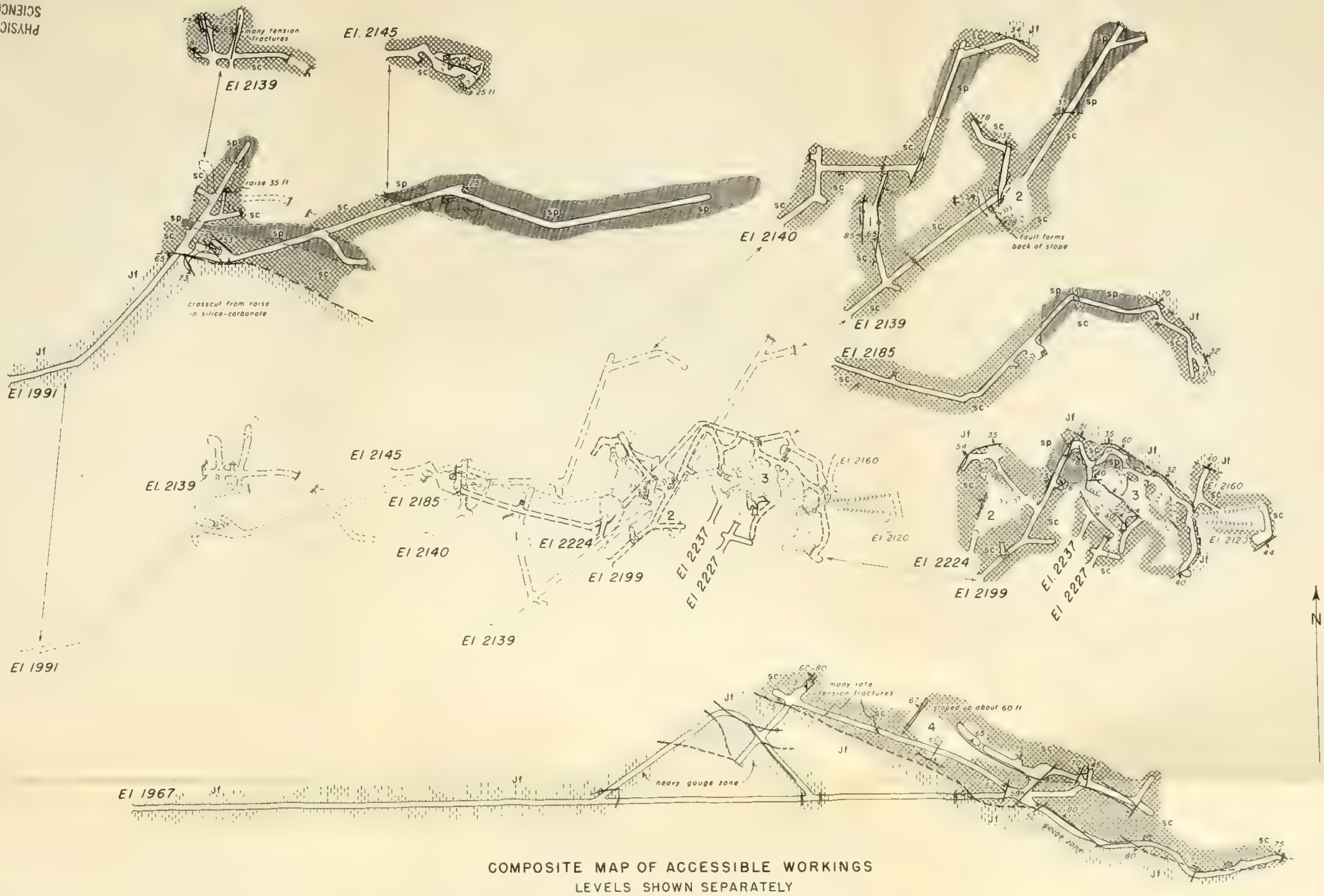
42. Apex Drilling Co., well no. "Flood" 1, sec. 14, T. 24 N., R. 3 W.
43. Crockett Drilling Syn., Inc. (Burgess & Goodale) well no 1, sec. 20, T. 24 N., R. 5 W.
44. Crockett Drilling Syn., Inc. well no 3, sec. 20, T. 24 N., R. 5 W.
45. General Petroleum Corp. "Dolan" no. 1, sec. 33, T. 23 N., R. 3 W.
46. Los Chicos Oil Co. well no. "Scharr" 1, sec. 27, T. 25 N., R. 4 W.
47. Marker Drilling Co. well no 1, sec. 31, T. 25 N., R. 5 W.
48. Northern Counties Pet. Co. well no. "Ewers-Mooney" 1, sec. 25, T. 24 N., R. 3 W.
49. Northern Oil & Gas Co., sec. 1, T. 23 N., R. 7 W.
50. Orland Oil Syn. Ltd. well no. "Johnston" 1, sec. 31, T. 23 N., R. 3 W.
51. Richfield Land Co., well no. 10, sec. 35, T. 25 N., R. 3 W.
52. Richfield Oil Corp. "Gallatin" 1, sec. 26, T. 25 N., R. 3 W.
53. Richfield Oil Corp. "Gallatin" 1A, sec. 26, T. 25 N., R. 3 W.
54. Stella, E. F., Trustee, well no. "Johnston" 2, sec. 30, T. 23 N., R. 4 W.
55. Tehama Co. Oil Co. & Hooker Dome Oil Co., well no. 1, sec. 24, T. 26 N., R. 4 W.
56. Texas Co. "Jelly Bend" 18-8, sec. 8, T. 29 N., R. 2 W.
57. Texas Co. "Walbridge" 1, sec. 32, T. 28 N., R. 2 W.
58. Texas Co. "Walbridge" 1A, sec. 32, T. 28 N., R. 2 W.
59. Tuscan Oil Co., well no. 1, sec. 25, T. 28 N., R. 4 W.

SAND AND GRAVEL

60. Draper & Adams, sec. 20, T. 27 N., R. 3 W.
61. Frederickson & Westbrook, sec. 30, T. 27 N., R. 3 W.
62. A. S. Jones and R. P. King, sec. 31, T. 28 N., R. 3 W.

Map
Map
Map
No.
No.
No.


GEOLOGIC MAP AND BLOCK DIAGRAM
OF THE
CLOVERDALE QUICKSILVER MINE
WESTERN MAYACMAS DISTRICT
SONOMA CO. CALIFORNIA
U.S. GEOLOGICAL SURVEY
MARCH 1943
OPEN WORKINGS MAPPED BY
E H BAILEY, J B CATHCART, P F FIX, D A PHOENIX, AND C.M. SWINNEY
CAVED WORKINGS COPIED FROM
COMPANY MAPS AND ADJUSTED
SCALE
40 30 20 10 0 40 FT
TRUE NORTH
REPORTED WORKINGS, POSITION UNCERTAIN
"HANGING WALL" CONTACT-LOCALLY FAULTED-1490 FT
"HANGING WALL" 1580 FT
"HANGING WALL" 1440 FT
"HANGING WALL" 1530 FT
"HANGING WALL" 1595 FT
"HANGING WALL" 1672 FT
"HANGING WALL" 1510 FT
CHERT BEGINS ON 1488 LEVEL
GREENSTONE BEGINS ON 1488 LEVEL
STOPED TO SURFACE, CAVED
SHALE IN BACK
REPORTED TO BE SANDSTONE
MINED IN OPEN CUT
1-2 FT OF GOUGE
CASSIN WORKINGS
BRITTON WORKINGS
NO. 5 ADIT
NO 6 ADIT
1557 FT
1572 FT
1554 FT
1595 FT
1486 FT
1527 FT
1510 FT
1436 FT
1331 FT
BLOCK DIAGRAM
SHOWING ONE OF SEVERAL INTERPRETATIONS
OF THE SCANT GEOLOGY AVAILABLE.
EXPLANATION
JURASSIC (?)
FRANCISCAN GROUP
SANDSTONE AND SHALE
CHERT
GREENSTONE
AREA REPORTED TO HAVE CONTAINED ORE
FAULT OR FAULTED DEPOSITIONAL CONTACT
ACCESSIBLE WORKINGS
INACCESSIBLE WORKINGS
BLOCKED WORKINGS
STOPE
SURFACE OPENING OR WORKINGS
SHAFT
HEAD OF WINZE
INCLINE, CHEVRONS POINT DOWN
ORE CHUTE
STRIKE AND DIP OF BEDS
PORTAL, BLOCKED



COMPOSITE MAP OF ACCESSIBLE WORKINGS
LEVELS SHOWN SEPARATELY
FOR GEOLOGY OF UPPER WORKINGS

SCALE
50 0 50 100 200 FEET

EXPLANATION

sc Silica-carbonate rock

sp Serpentine

Jf Sandstone and shale
Franciscan group

Fault

Foliation

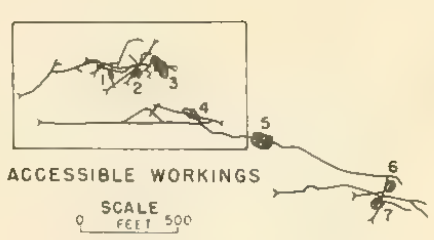
Gradational contact

Stope

Inclined workings, chevrons point down, vertical interval 5 feet

Head, foot, raise or winze

Caved workings



INDEX MAP FOR STOPES

STOPE NAMES
1 West Geyser stope
2 East Geyser stope
3 Baumeister stope
4 Daylight stope
5 Pinschower stope
6 Geyserville stope
7 Graham stope

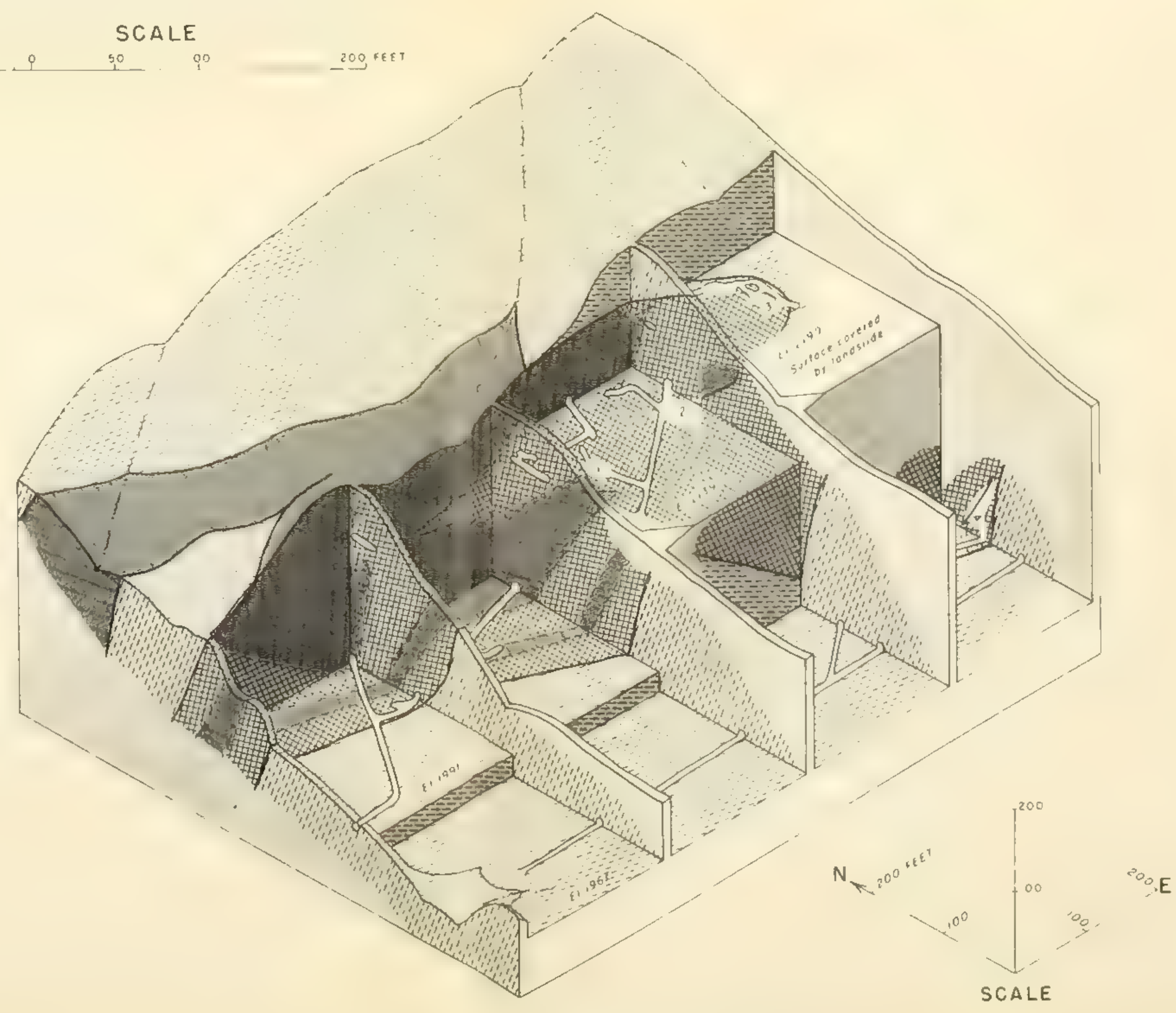
GEOLOGIC MAP AND BLOCK DIAGRAM OF THE

CULVER-BAER MINE

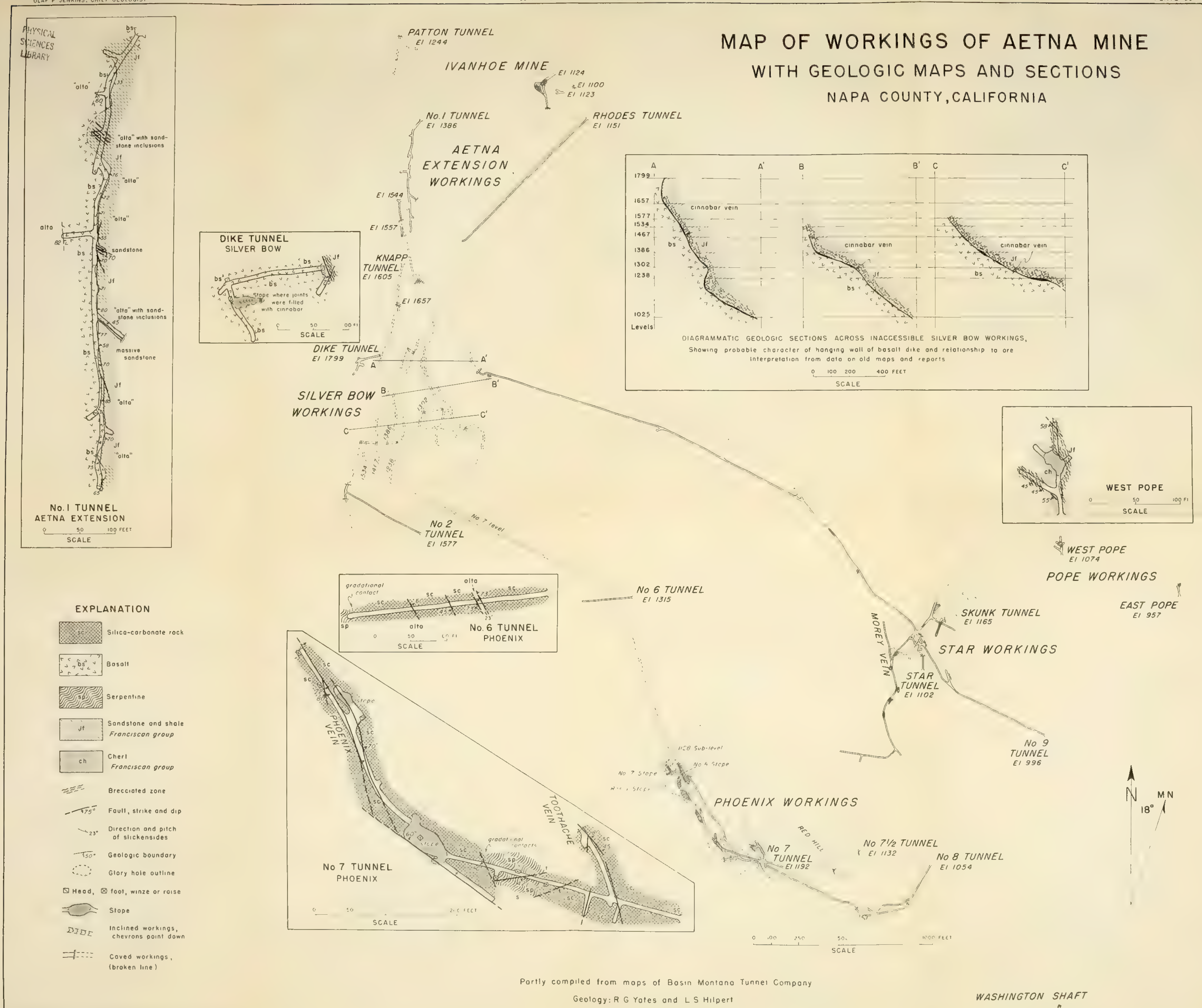
SONOMA COUNTY, CALIFORNIA

By Edgar H Bailey, J B Cathcart, Philip F Fix,
Fred B Roberts, and C M Swinney

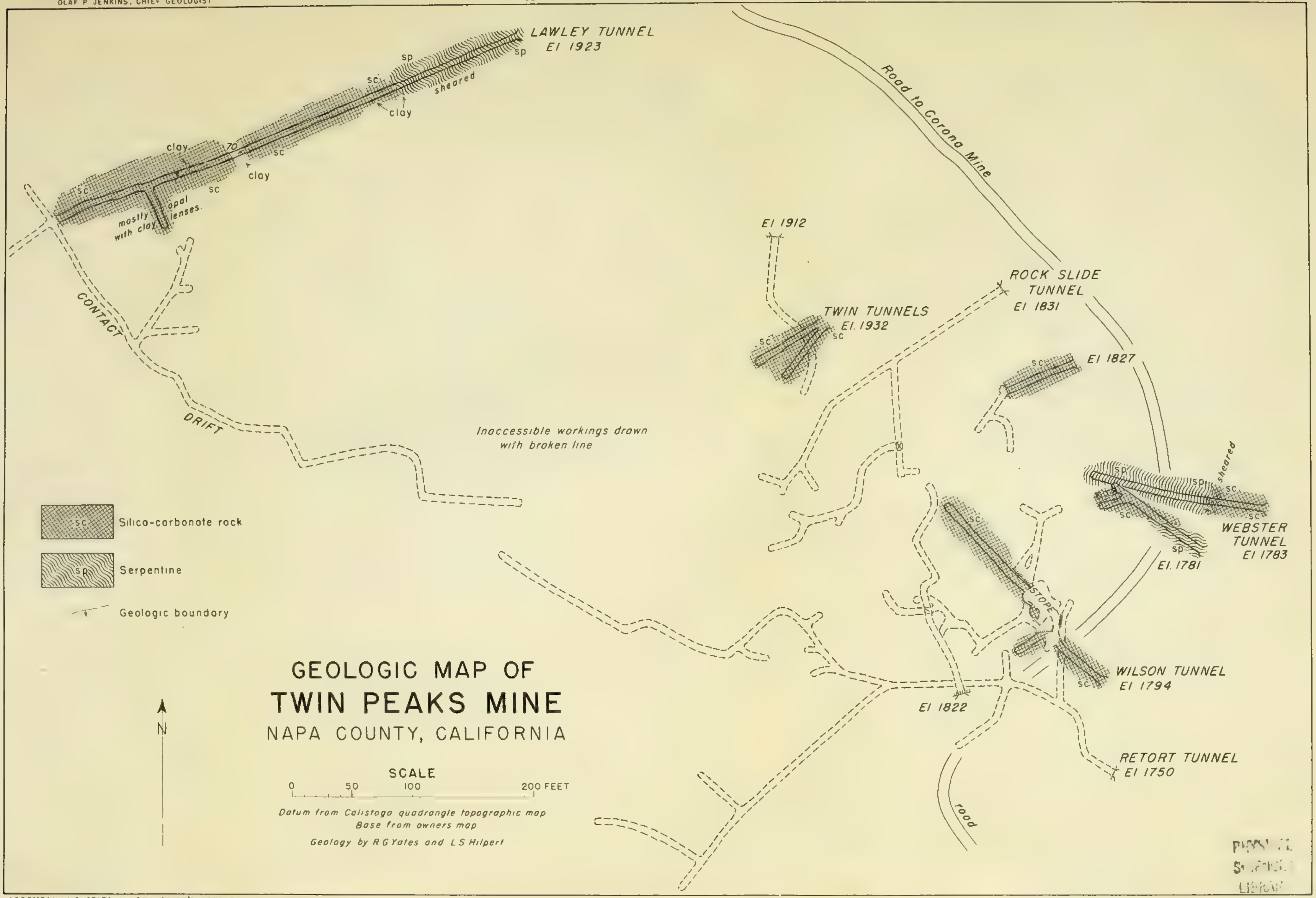
1941–1943

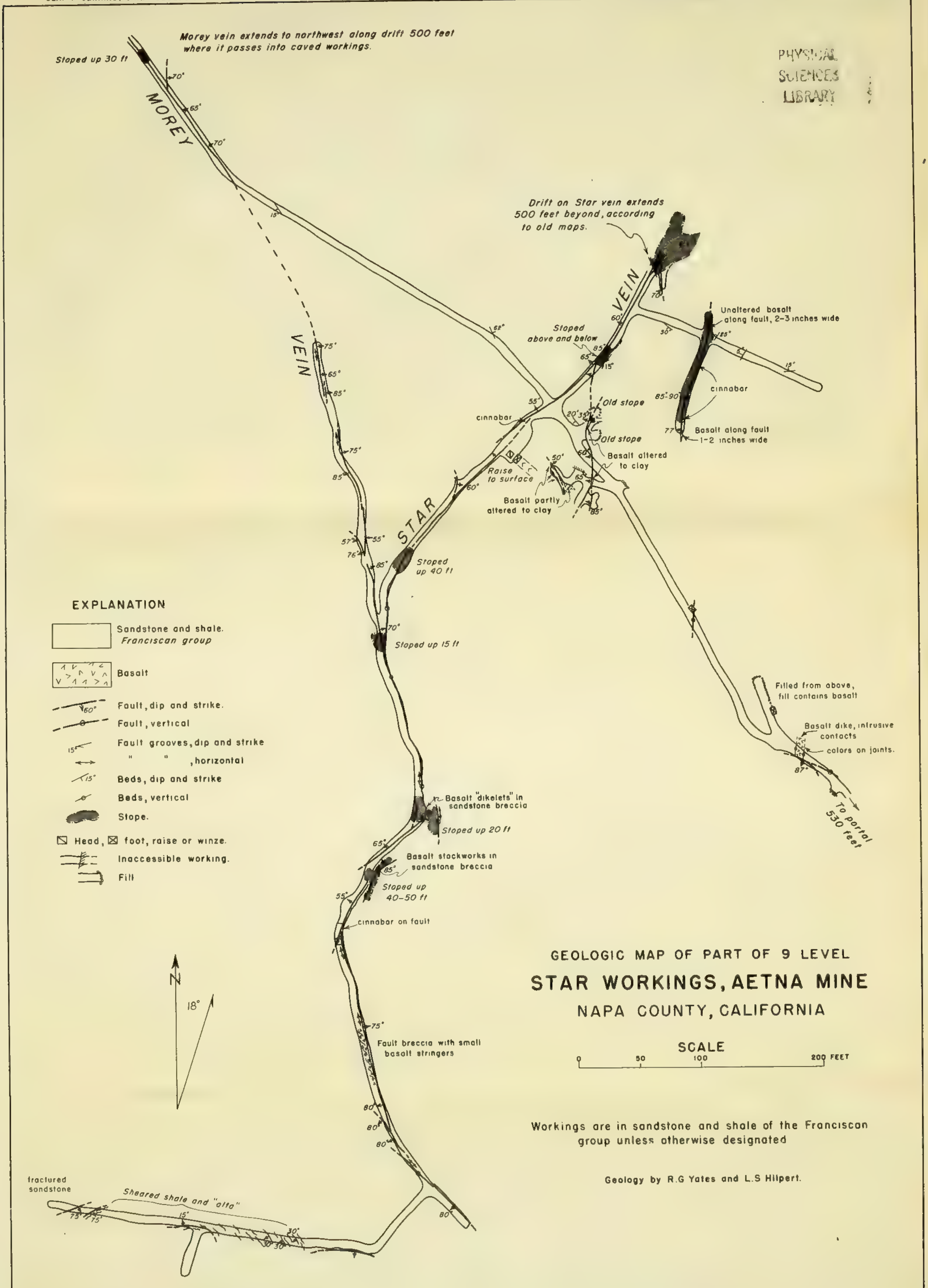


BLOCK DIAGRAM OF PART OF ORE ZONE


MAP OF WORKINGS OF AETNA MINE
WITH GEOLOGIC MAPS AND SECTIONS
NAPA COUNTY, CALIFORNIA
PATTON TUNNEL
El 1244
IVANHOE MINE
El 1124
El 1100
El 1123
No.1 TUNNEL
El 1386
RHODES TUNNEL
El 1151
AETNA EXTENSION WORKINGS
El 1544
El 1557
KNAPP TUNNEL
El 1605
El 1657
DIKE TUNNEL
El 1799
SILVER BOW WORKINGS
No 2 TUNNEL
El 1577
No 7 level
No 6 TUNNEL
El 1315
MOREY VEIN
SKUNK TUNNEL
El 1165
STAR WORKINGS
STAR TUNNEL
El 1102
No 9 TUNNEL
El 996
WEST POPE
El 1074
POPE WORKINGS
EAST POPE
El 957
1128 Sub-level
No 7 Stope
No 4 Stope
PHOENIX WORKINGS
RED HILL
No 7 TUNNEL
El 1192
No 7½ TUNNEL
El 1132
No 8 TUNNEL
El 1054
18°
MN
N
0 100 250 500 1000 FEET
SCALE
WASHINGTON SHAFT
No.1 TUNNEL
AETNA EXTENSION
"alta"
"alta" with sandstone inclusions
sandstone
massive sandstone
bs
Jf
0 50 100 FEET
SCALE
DIKE TUNNEL
SILVER BOW
Stope where joints were filled with cinnabar
0 50 100 Ft
SCALE
DIAGRAMMATIC GEOLOGIC SECTIONS ACROSS INACCESSIBLE SILVER BOW WORKINGS,
Showing probable character of hanging wall of basalt dike and relationship to ore
Interpretation from data on old maps and reports
cinnabar vein
Levels
1799
1657
1577
1534
1467
1386
1302
1238
1025
0 100 200 400 FEET
SCALE
WEST POPE
ch
0 50 100 Ft
SCALE
No. 6 TUNNEL
PHOENIX
gradational contact
alta
sc
sp
0 50 100 Ft
SCALE
No 7 TUNNEL
PHOENIX
PHOENIX VEIN
TOOTHACHE VEIN
gradational contacts
stope
0 50 200 FEET
SCALE
EXPLANATION
Silica-carbonate rock
Basalt
Serpentine
Sandstone and shale
Franciscan group
Chert
Franciscan group
Brecciated zone
Fault, strike and dip
Direction and pitch of slickensides
Geologic boundary
Glory hole outline
Head, foot, winze or raise
Stope
Inclined workings, chevrons point down
Caved workings, (broken line)
Partly compiled from maps of Basin Montana Tunnel Company
Geology: R G Yates and L S Hilpert


GEOLOGIC MAP OF PART OF 8 LEVEL
PHOENIX WORKINGS, AETNA MINE
NAPA COUNTY, CALIFORNIA
50 0 50 100 200 FEET
SCALE
Geology by R G Yates and L S Hilpert
EXPLANATION
Silica-carbonate rock
Serpentine
Sandstone and shale
Franciscan group.
Black gouge or "alta".
Breccia showing lineation
Fault, strike and dip.
Fault, vertical
Fault grooves, dip and strike
Fault grooves, horizontal
Gradational contact with dip
Foot of raise
Inaccessible workings
N
M.N.
18°
PHOENIX VEIN
TOOTHACHE VEIN
Stoped up 10-12 ft
cinnabar in back
Stoped up
cinnabar
caved
cinnabar
81 ft above 8 level
72 ft above 8 level
56 ft above 8 level
cinnabar
Raise 45 ft on contact
Contains Jf breccia
raise 16 ft
cinnabar in tight slip
PORTAL 8 LEVEL
Elev. 1054
Stoped up 15-18 ft
contact with "alta" in back of stope
Stoped up 20 ft
alta

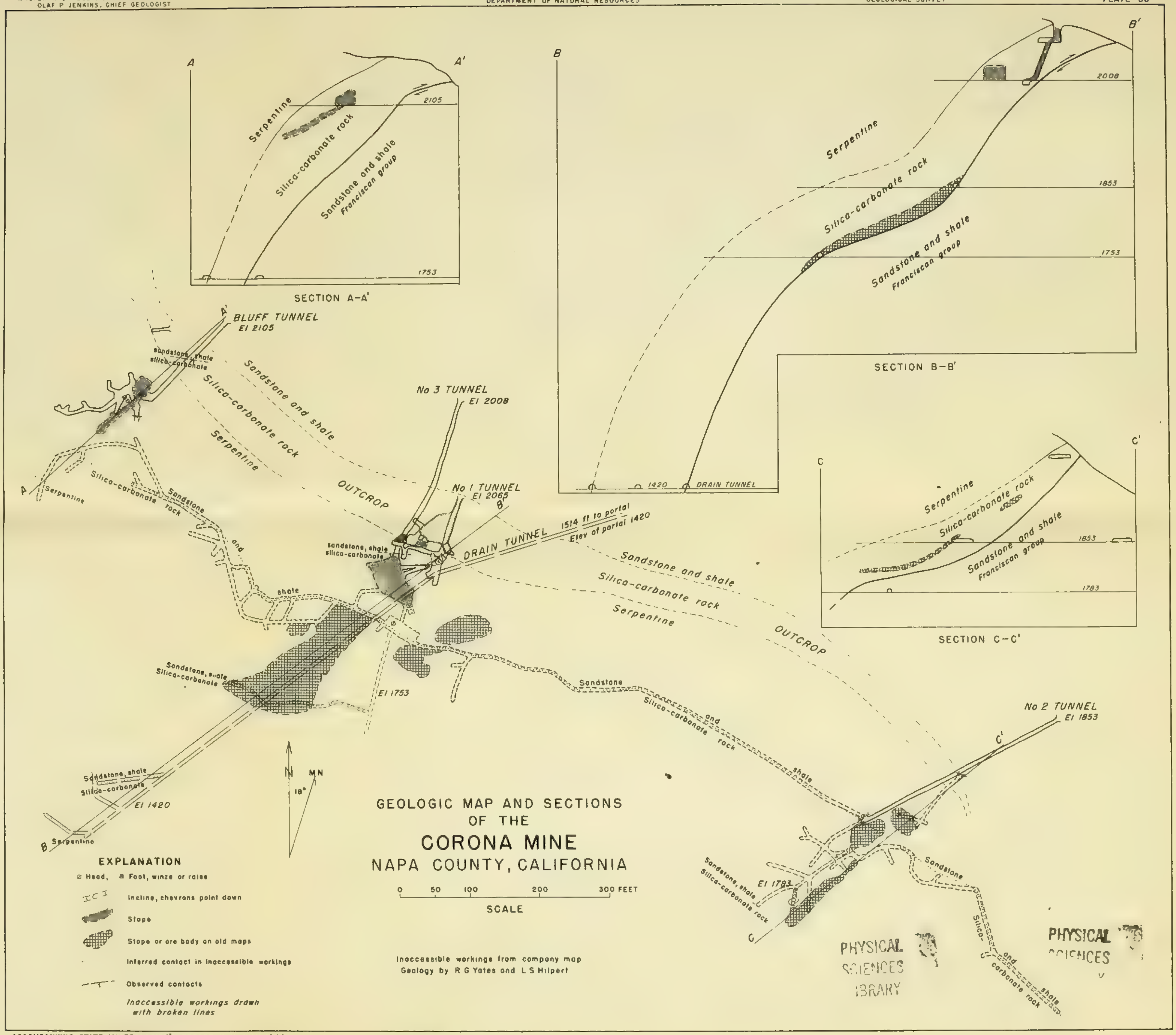

GEOLOGIC MAP OF
TWIN PEAKS MINE
NAPA COUNTY, CALIFORNIA
SCALE
0 50 100 200 FEET
Datum from Calistoga quadrangle topographic map
Base from owners map
Geology by R.G. Yates and L.S. Hilpert
Silica-carbonate rock
Serpentine
Geologic boundary
N
Inaccessible workings drawn with broken line
LAWLEY TUNNEL
El 1923
sheared
clay
mostly with clay
opal lenses
70
CONTACT
DRIFT
Road to Corona Mine
El 1912
TWIN TUNNELS
El. 1932
ROCK SLIDE
TUNNEL
El 1831
El 1827
WEBSTER
TUNNEL
El 1783
El. 1781
STOPE
WILSON TUNNEL
El 1794
El 1822
RETORT TUNNEL
El 1750
road



GEOLOGIC MAP OF PART OF 9 LEVEL

STAR WORKINGS, AETNA MINE

NAPA COUNTY, CALIFORNIA



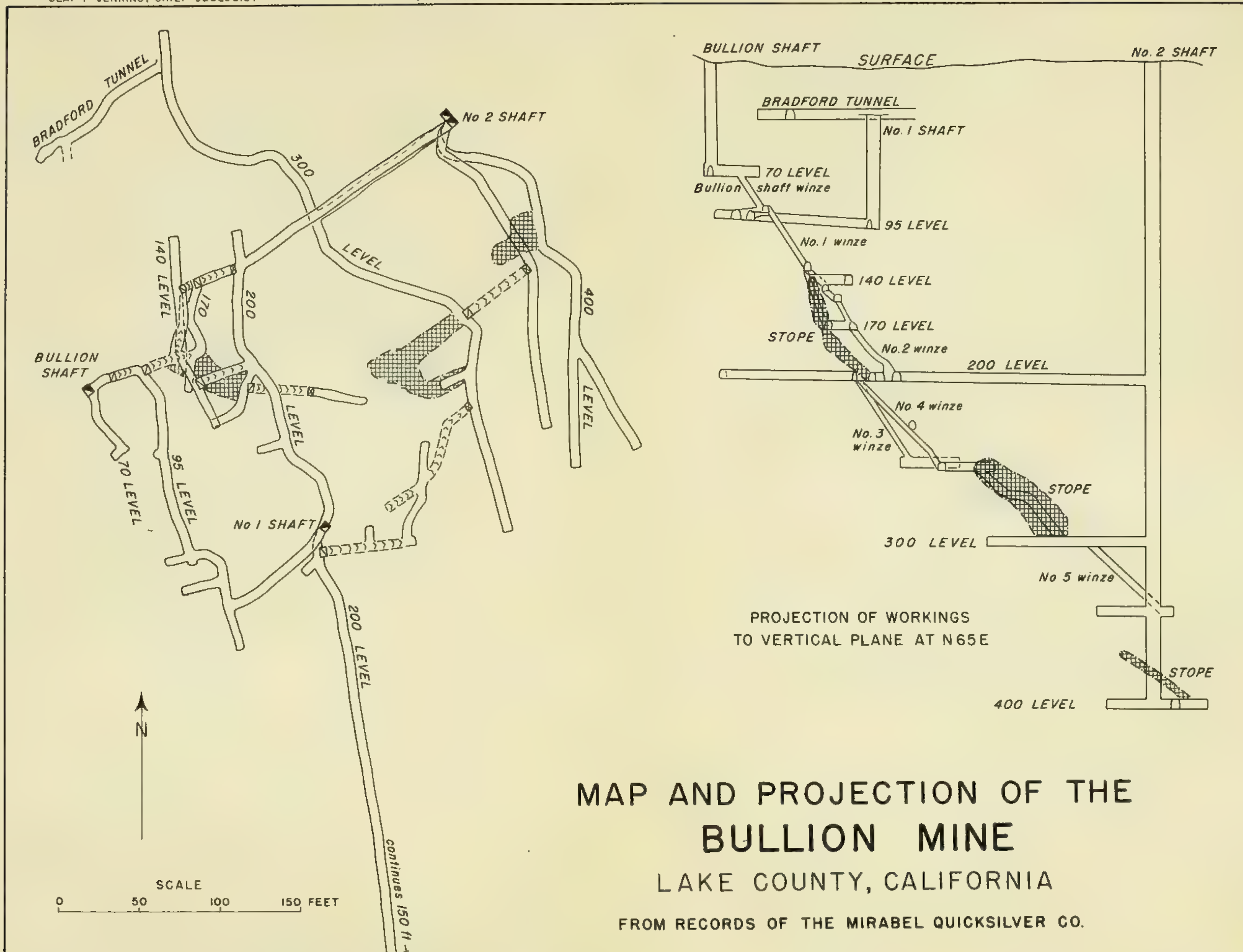
GEOLOGIC MAP AND SECTIONS
OF THE
CORONA MINE
NAPA COUNTY, CALIFORNIA

DIVISION OF MINES
WALTER W BRADLEY, STATE MINERALOGIST
OLAF P JENKINS, CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

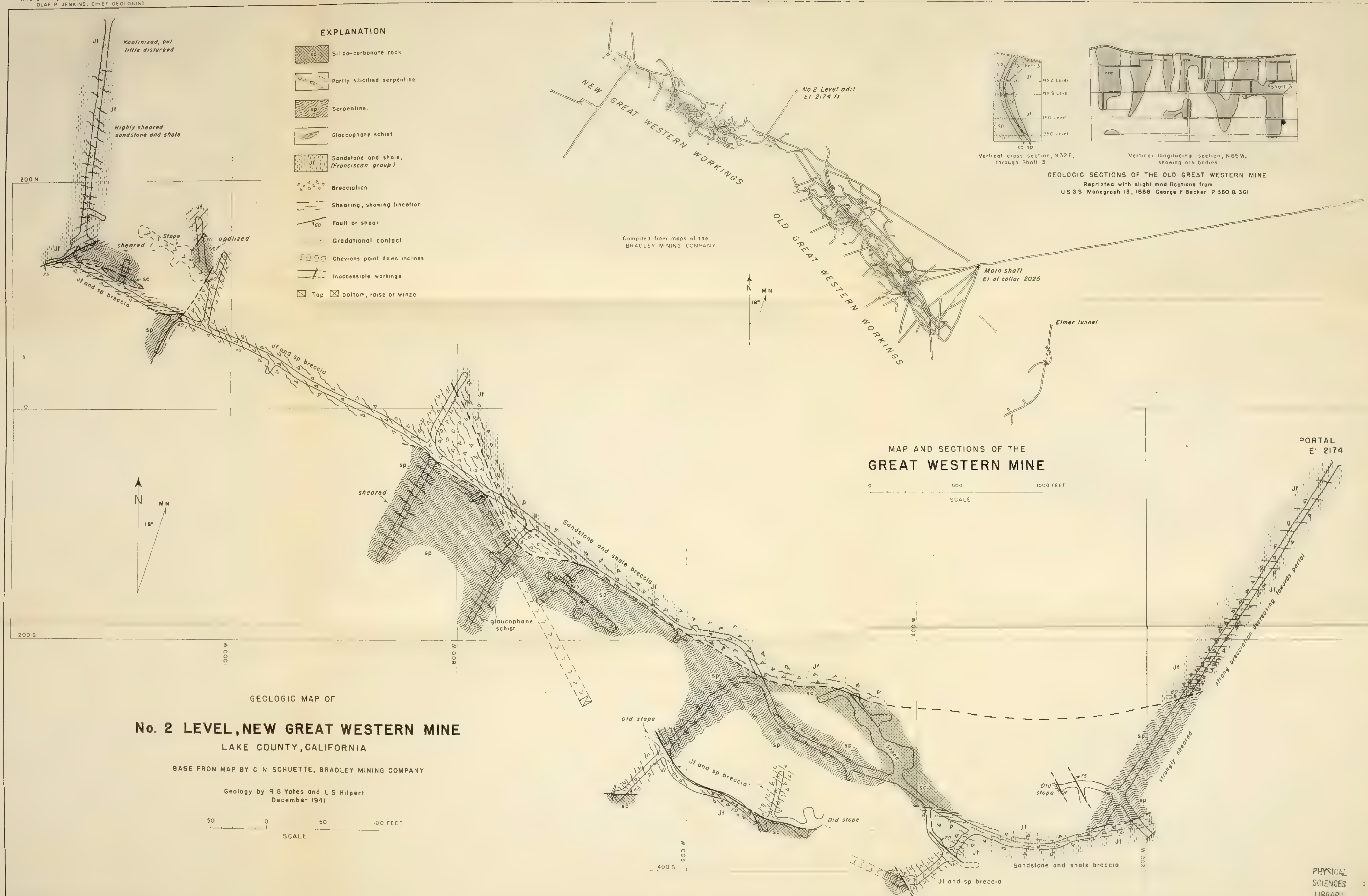
PLATE 40



MAP AND PROJECTION OF THE
BULLION MINE
LAKE COUNTY, CALIFORNIA

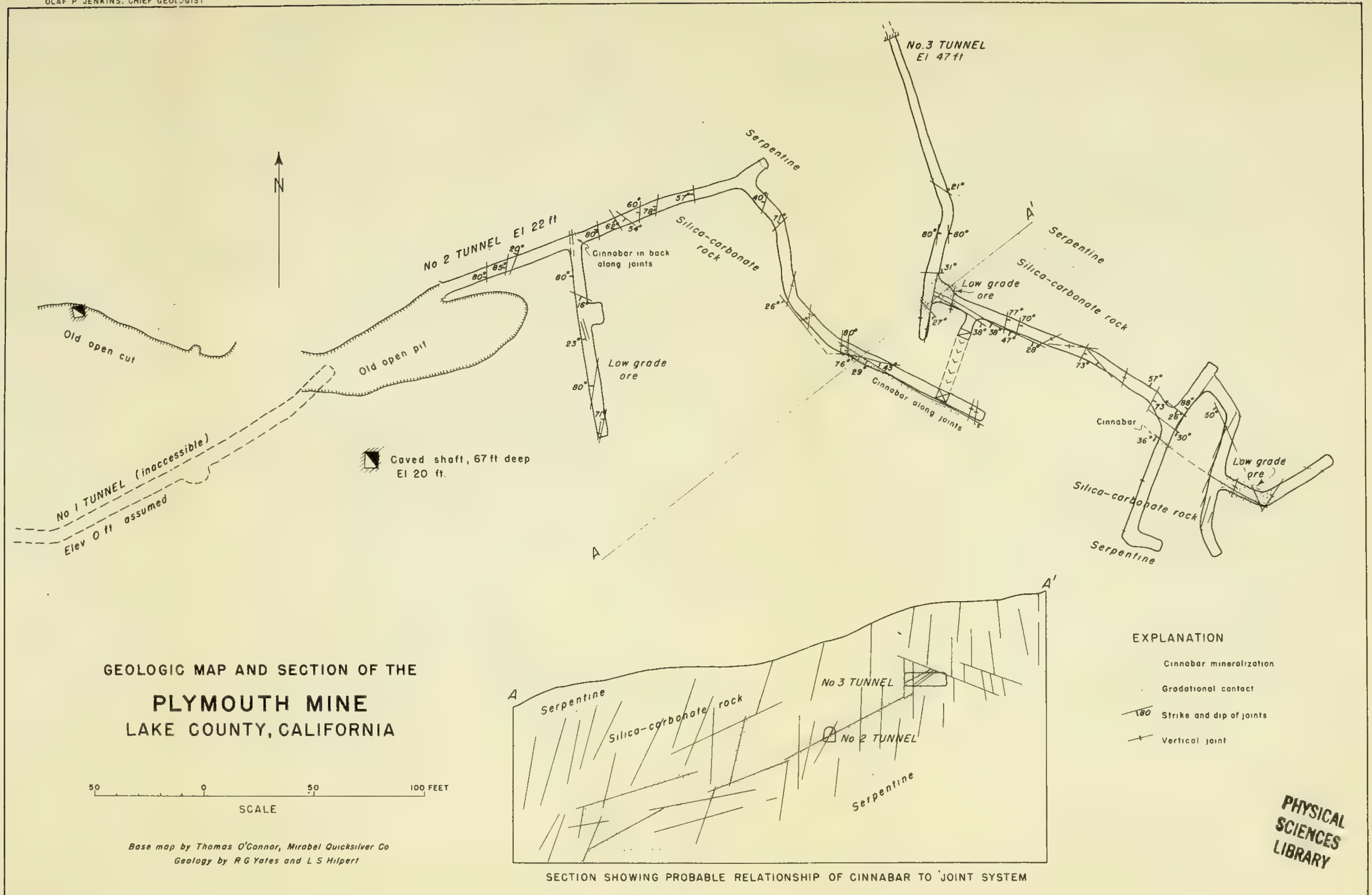
FROM RECORDS OF THE MIRABEL QUICKSILVER CO.

ACCOMPANYING STATE MINERALOGIST'S REPORT XLII JULY 1946


EXPLANATION
Silica-carbonate rock
Partly silicified serpentine
Serpentine
Glaucophane schist
Sandstone and shale, (Franciscan group)
Brecciation
Shearing, showing lineation
Fault or shear
Gradational contact
Chevrons point down inclines
Inaccessible workings
Top bottom, raise or winze
Kaolinized, but little disturbed
Highly sheared sandstone and shale
Stope
sheared
opalized
Jf and sp breccia
Sandstone and shale breccia
glaucophane schist
Old stope
strongly sheared
strong brecciation decreasing towards portal
PORTAL
El 2174
200 N
0
200 S
400 S
1000 W
800 W
600 W
400 W
200 W
N
MN
18°
NEW GREAT WESTERN WORKINGS
OLD GREAT WESTERN WORKINGS
No 2 Level adit
El 2174 ft
Main shaft
El of collar 2025
Elmer tunnel
Compiled from maps of the BRADLEY MINING COMPANY
Vertical cross section, N32E, through Shaft 3
Vertical longitudinal section, N65W, showing ore bodies
Shaft 3
No 2 Level
No 9 Level
150 Level
250 Level
ore
GEOLOGIC SECTIONS OF THE OLD GREAT WESTERN MINE
Reprinted with slight modifications from
USGS Monograph 13, 1888 George F Becker P 360 & 361
MAP AND SECTIONS OF THE
GREAT WESTERN MINE
0
500
1000 FEET
SCALE
GEOLOGIC MAP OF
No. 2 LEVEL, NEW GREAT WESTERN MINE
LAKE COUNTY, CALIFORNIA
BASE FROM MAP BY C N SCHUETTE, BRADLEY MINING COMPANY
Geology by R G Yates and L S Hilpert
December 1941
50
0
50
100 FEET
SCALE


EXPLANATION
Silica-carbonate rock
Silicified serpentine
Transitional from sp to sc
Serpentine
Greenstone
Sandstone and shale
Silicified sandstone and shale
Franciscan group
Dolomite vein
Breccia or shear zone
Fault, dip and strike
Vertical fault
Contact, gradational or indefinite
Head, foot, winze or raise
Inaccessible workings
Inclined workings
GEOLOGIC MAP
OF THE
BRADFORD WORKINGS
MIRABEL MINE
LAKE COUNTY, CALIFORNIA
SCALE
200 FEET
Base from company maps
Geology by R. G. Yates and L. S. Hilpert
November 1941
120 LEVEL
180 LEVEL
300 LEVEL
345 slope
371 slope
September slope
Vineyard slope
50 Sub-level
80 Sub-level
110 Sub-level
160 Sub-level
BRADFORD SHAFT
East slope
Old West slope
N

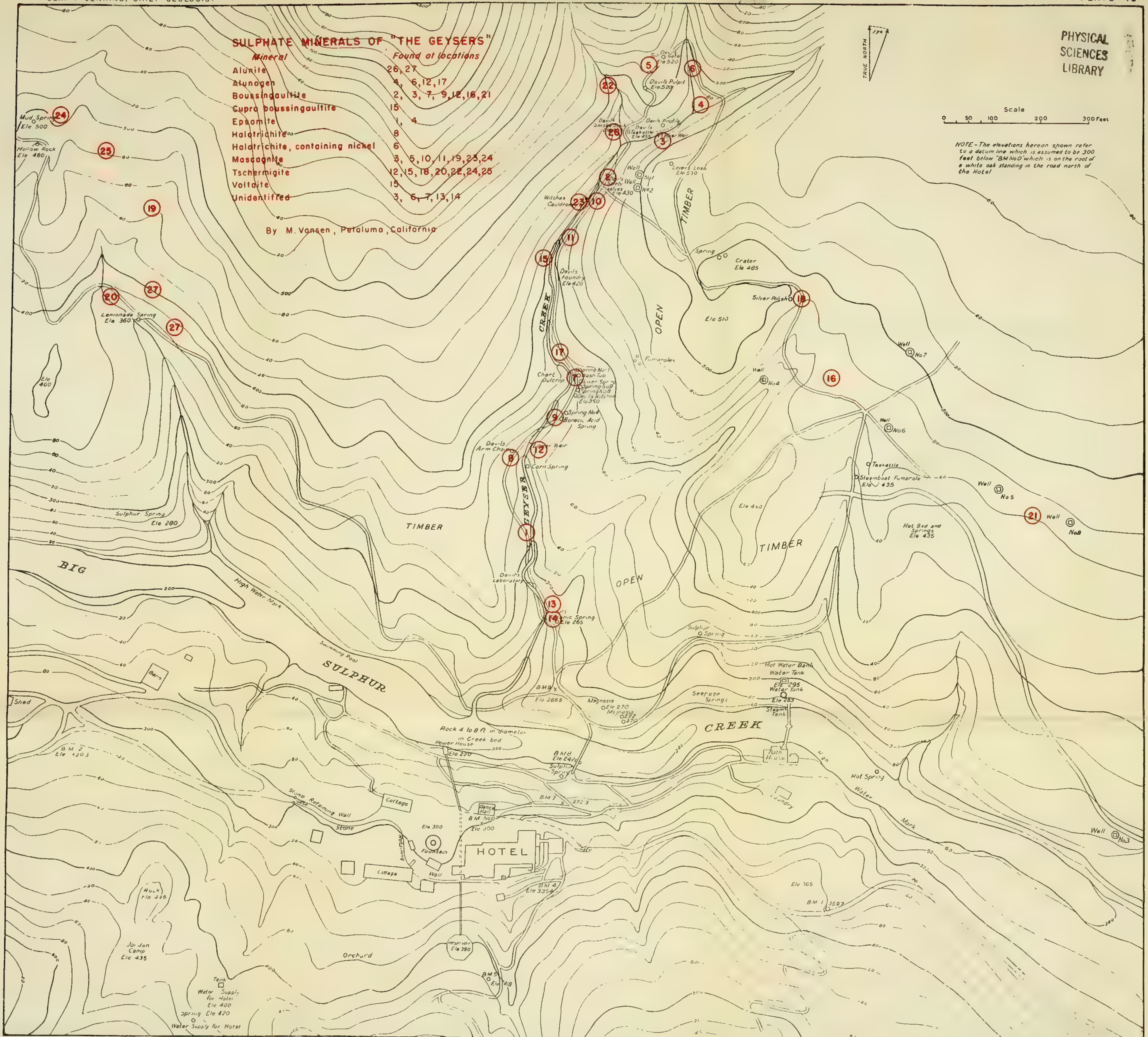
ACCOMPANYING STATE MINERALOGIST'S REPORT XLII JULY 1946


No.3 TUNNEL
El 47 ft
Serpentine
No 2 TUNNEL El 22 ft
Cinnabar in back along joints
Silica-carbonate rock
Low grade ore
Old open cut
Old open pit
Caved shaft, 67 ft deep
El 20 ft.
No 1 TUNNEL (inaccessible)
Elev 0 ft assumed
Cinnabar along joints
Cinnabar
A
A'
N
GEOLOGIC MAP AND SECTION OF THE
PLYMOUTH MINE
LAKE COUNTY, CALIFORNIA
50 0 50 100 FEET
SCALE
Base map by Thomas O'Connor, Mirabel Quicksilver Co
Geology by R G Yates and L S Hilpert
EXPLANATION
Cinnabar mineralization
Gradational contact
80 Strike and dip of joints
Vertical joint
No 3 TUNNEL
No 2 TUNNEL
SECTION SHOWING PROBABLE RELATIONSHIP OF CINNABAR TO JOINT SYSTEM
PHYSICAL SCIENCES LIBRARY

DIVISION OF MINES
WALTER W BRADLEY, STATE MINERALOGIST
OLAF P JENKINS, CHIEF GEOLOGIST

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

PLATE 48

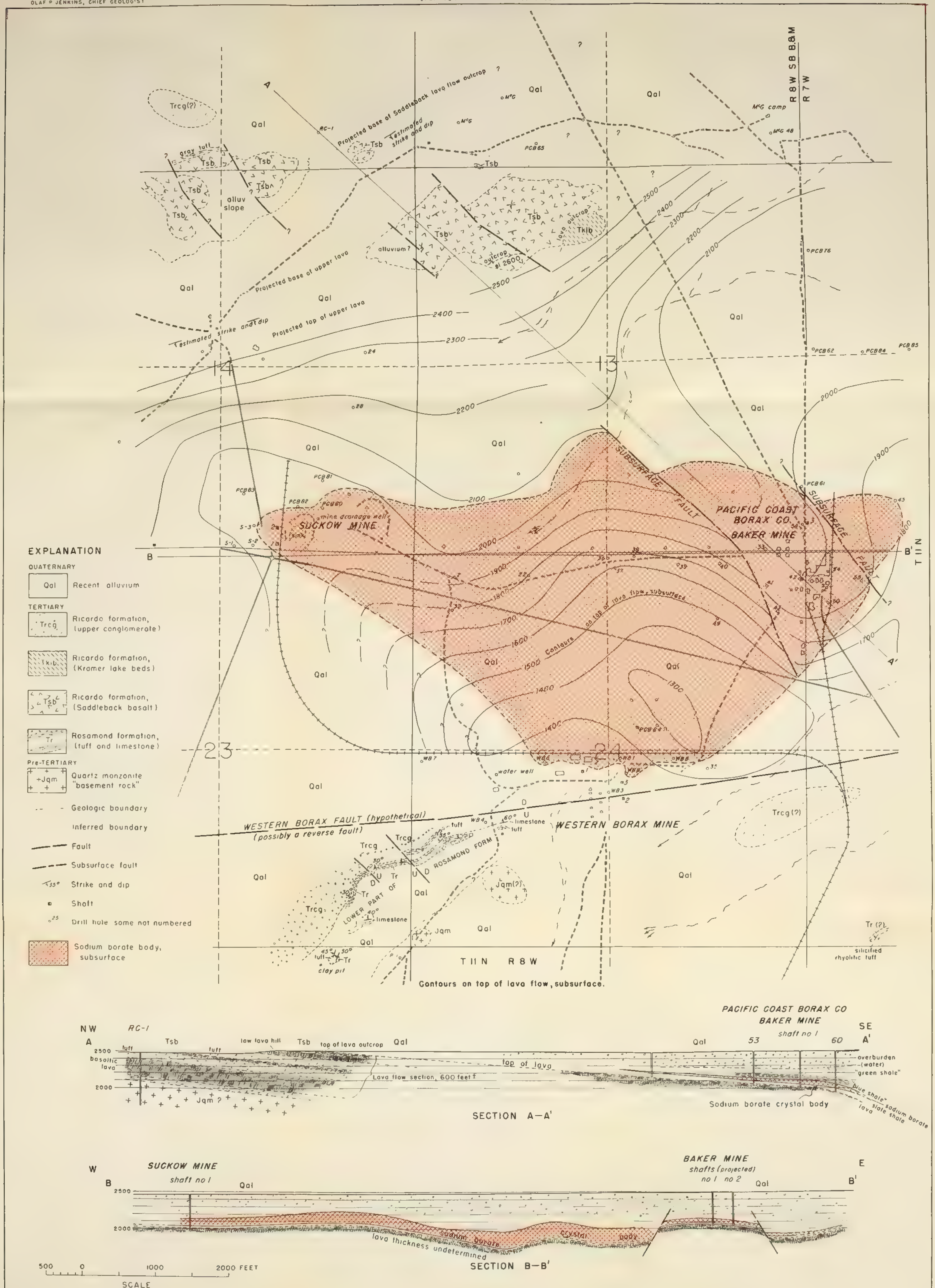


ACCOMPANYING STATE MINERALOGIST'S REPORT XLII JULY 1946

MAP OF "THE GEYSERS" AREA, SONOMA COUNTY, CALIFORNIA
SHOWING MINERAL LOCATIONS

Base Map from Carnegie Institution of Washington, Publication No. 378

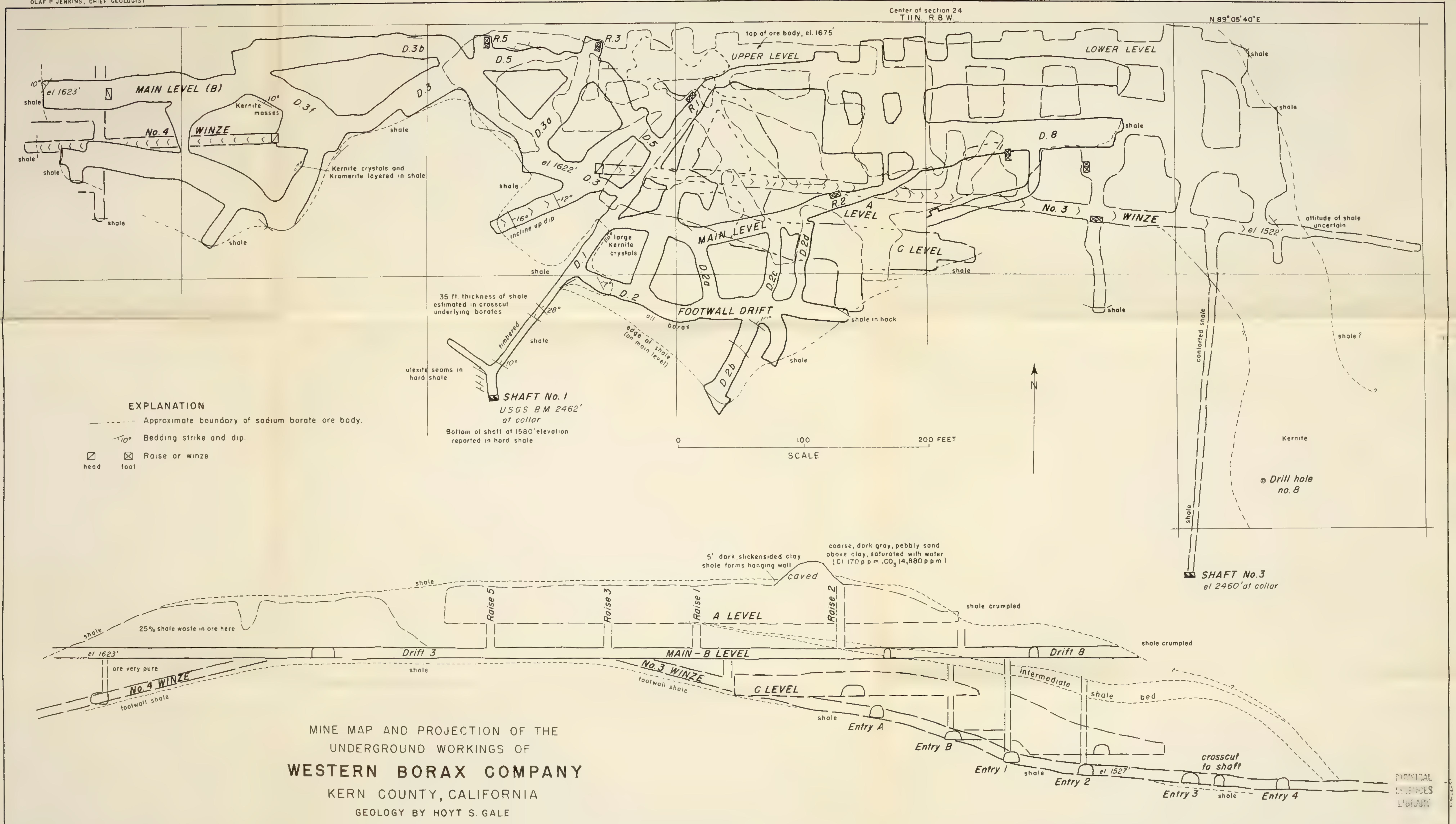

PHYSICAL SCIENCES LIBRARY
GEOLOGIC MAP OF THE
KRAMER BORATE DISTRICT
KERN AND SAN BERNARDINO COUNTIES
CALIFORNIA
By Hoyt S. Gale and Hoyt Rodney Gale. 1935
EXPLANATION
QUATERNARY
Qal Recent alluvium
Qoal Older alluvium (terrace remnants)
TERTIARY
Trcg Ricardo formation (upper conglomerate)
Tklb Ricardo formation (Kramer lake beds)
Tsb Ricardo formation (Saddleback basalt)
Tr Rosamond formation (tuff, limestone, chert; sandstone near base)
Pre-TERTIARY
Jqm Quartz monzonite
JRa Amargo formation (tuffs, pyroclastics; including quartz porphyry intrusives)
Known fault
Probable fault
Fault in borate deposits
Geologic boundary
Inferred boundary
Beds or flows, strike and dip
Approximate limit of buried calcium borate deposits
Limit of sodium borate body
Drill hole, some not numbered
SCALE
1 0.5 0 1 2 Miles
Contour interval 5 feet Datum is mean sea level
Topographic base from U.S.G.S. advance sheet.
APPROXIMATE MEAN DECLINATION 1932
SECTION A—A'
Stone House Hills
CALCIUM BORATE (subsurface)
SODIUM BORATE BODY
SUCKOW BORAX CO Mill
SUCKOW BORAX CO Mine
PACIFIC COAST BORAX CO Mine and mill
WESTERN BORAX CO Mine and mill
WESTERN BORAX FAULT
RUSSELL FAULT (subsurface)
MYRICK
SWANSON
RUSSELL-CRITES
PRUITT 1
KOHLER 1
MARSHALL-BOND
BALLING
STROM
RUSSELL
SUCKOW
BURNHAM
SUPERIOR 2



GEOLOGY BY HOYT S GALE

GEOLOGIC MAP AND SECTIONS OF THE CENTRAL PART OF
KRAMER BORATE DISTRICT, KERN COUNTY, CALIFORNIA

ACCOMPANYING REPORT XLII OCTOBER 1946



MINE MAP AND PROJECTION OF THE
UNDERGROUND WORKINGS OF
WESTERN BORAX COMPANY
KERN COUNTY, CALIFORNIA
GEOLOGY BY HOYT S. GALE